UNIVERSITY OF WINCHESTER

The influence of somatotype on acute and chronic responses to resistance exercise

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This thesis is dedicated to my nan, Margaret Harper, who passed away aged 94 on 8th January 2020 when I was completing my write-up. She never got to see me complete this but she always believed I would.

"You raise me up to more than I can be"

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Abstract

The influence of somatotype on acute and chronic responses to resistance exercise

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The relationship between somatotype and successful athletic performance is well established. Somatotype has also been linked to physiological function. This thesis assessed whether somatotype is related to anaerobic (particularly strength) performance and, how it might contribute to acute and chronic responses to resistance exercise in untrained people.

The first study demonstrated a link between somatotype rating and strength performance (Chapter 3). Mesomorphy was positively associated with upper- (chest press) and lower-body (back squat) strength performance. Mesomorphy was the best predictor of upper-body strength (31.4% of variance). A combination of mesomorphy and ectomorphy rating was the strongest predictor of 3 repetition maximum (RM) back squat performance (38.8% of variance). Chapter 4 investigated the reliability of categorising somatotypes from dominant ratings and concluded that categories should remain simple (e.g., only use primary dominant category), and be as precise as possible. Furthermore, with untrained participants, measures of muscle thickness (MT) were reliable when using ultrasound. Chapter 5 assessed whether there were any differences between simple somatotype groups in measures of MT. MT at the biceps brachii and biceps femoris was higher for mesomorphs than ectomorphs. However, baseline salivary cortisol and testosterone and resistance exercise-induced changes (acute responses) in these two measures were not different between somatotypes. The final study (Chapter 6) examined responses to an 8-week resistance training programme in untrained participants. Ectomorphs experienced an overall 26.4% greater increase in

back squat 10RM strength over the training period compared to the mesomorphs. Mesomorphs experienced greater hypertrophy, particularly in the triceps brachii and biceps femoris. Measurement of muscle activity and changes in muscle blood flow were unable to help explain these findings. In summary, in an untrained population, somatotype is related to baseline strength performance, muscle size and adaptations to resistance training. Futhermore, somatotype can reliably assess strength performance outputs and responses to resistance training.

Keywords: mesomorph, ectomorph, endomorph, reliability, muscle thickness, strength

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List of Abbreviations

ACE = Angiotensin-I converting enzyme

ACSM = American College of Sports Medicine

AD = analogue to digital

ANOVA = analysis of variance

AU = arbritary units

BB = bicep brachii

BF = biceps femoris

C = cortisol

CAGFT = corrected arm girth flexed and tensed

CI = confidence interval

CRAG = corrected relaxed arm girth

CSA = cross sectional area

CT = computerised tomography

CV = coefficient of variation

EMG = electromyography

FI = fasting insulin

FVC = forced vital capacity

HDL-C = high density lipoprotein cholesterol

HHb = deoxyhaemaglobin

HWR = height weight ratio

ICC = intraclass correlation coefficient

ISAK = International Society for the Advancement of Kinanthropometry

LOA = limits of agreement

MAP = maximal aerobic power

MD = migratory distance

MT = muscle thickness

MZ = monozygotic

NIRS = near-infrared spectroscopy

O2Hb = oxyhaemaglobin

PA = pennation angle

PAm = peak amplitude

PFI = physical fitness index

P-MRS = phosphorous magnetic resonance spectroscopy

RER = respiratory exchange ratio

RF = rectus femoris

RM = repetition maximum

SAD = somatotype attitudinal distance

SAM = somatotype attitudinal mean

SBP = systolic blood pressure

SD = standard deviation

SDD = smallest detectable difference

SEM = standard error of the mean

T = testosterone

TB = triceps brachii

T:C = testosterone to cortisol ratio

TEM = technical error of measurement

TG = triglycerides

THb = total haemoglobin

TSI = tissue saturation index

TTP = time to peak

$\dot{V}O_{2max}$ = maximal oxygen uptake

Research Outputs

Outputs from the thesis:

Publications:

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Ryan-Stewart, H., Faulkner, J., Jobson, S. (2018). The influence of somatotype on anaerobic performance. *PLoS ONE*, 13(5): e0197761 (Appendix 1a).

Ryan-Stewart, H., Felton, M., Crane, A., Cotterill, S., and Jobson, S. (2016). Reliability of the Terason ultrasound for measurement of muscle thickness and pennation angle. *Journal of Sports Sciences*, 34 (S1): s30.

Ryan-Stewart, H., Cotterill, S., and Jobson, S. (2015). The impact of technical error of measurement on somatotype categorisation. *Journal of Sports Sciences*, 33: s37-8.

Ryan, H., and Jobson, S. (2014). The relation between somatotype and maximal 30-s cycle ergometer sprint performance. *Journal of Sports Sciences*, 32 (S2): p.97.

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Ryan-Stewart, H., Cotterill, S., and Jobson, S. (2015). The impact of technical error of measurement on somatotype categorisation, *BASES Annual Conference,* St. George's Park, UK.

Ryan, H., and Jobson, S. (2014). The relation between somatotype and maximal 30-s cycle ergometer sprint performance. *BASES Annual Conference,* St. George's Park, UK.

Chapter 1: Introduction

The scientific measurement of phenotype is well-established, with historical measurements dating back to the ancient Greek physician Hippocrates and his proposed typus phthisicus and typus apoplecticus dichotomy (c. 460 - 370BC) (Carter *et al.*, 1983; Withers *et al.*, 1986; Duquet and Carter, 2009; Carter and Stewart, 2012). Body composition is a factor that contributes to performance in many sports (Olds, 2001; Slater *et al.,* 2005; Lewandowska *et al.*, 2011; Kandel *et al.*, 2014), and has been shown to influence physiological function (Norton *et al.*, 1996; Pilis *et al.*, 1997; Lazarus *et al.,* 1998; Bolonchuk *et al.*, 2000; Ackland, 2008; Lewandowska *et al.*, 2011). For example, excess adipose tissue may increase metabolic burden (Withers *et al.*, 1986; Norton *et al.*, 1996), and reduce elements of respiratory function (Lazarus *et al.*, 1998). Whilst excess muscle mass is associated with greater strength performance (Draper and Marshall, 2013).

A summary of a person's overall physique is often given using somatotype, a method originally developed in the 1940s by Sheldon, Stevens and Tucker (1940). It was later modified by JE Lindsay Carter and Barbara Honeyman-Heath to include anthropometric measurements and create the Heath-Carter method currently used to establish somatotype (Heath and Carter, 1966; 1967). A somatotype rating gives an overview of physique by using measures relating to body shape and composition, assessing adiposity (fatness), musculo-skeletal robustness, and linearity (resemblance to a straight line). A person's physique can then be identified by assigning them a three-numeral rating (endomorphy-mesomorphy-ectomorphy), with each representing the aforementioned descriptions in order (Carter and Stewart, 2012). Heath and Carter (1967) indicated that somatotype rated current morphology; a description of the shape and composition of physique that is dissociated from size and fits both sexes and all ages (Carter *et al*., 1983). The classification of physique by somatotype gives a reliable variability description in humans regardless of differences in age, sex, race, genetics, climate, health, diet or physical activity (Heath and Carter, 1971; Hebbelinck *et al.,* 1973; Carter and Heath, 1990; Carter, 1996, Carter, 2002). Somatotyping is considered a relatively uncomplicated and economical method to assess physique even with the advent of modern imaging (Peeters *et al.,* 2007).

It is well-documented that a person's anthropometric dimensions have an influence over their ability to perform physical activity (Norton *et al.*, 1996). Indeed, in the athletic population specific physiques, particularly somatotypes, have been highly associated with success in specific sporting competitions (Carter, 1970). Whilst research has demonstrated that exercise and diet can influence

a person's somatotype over an extended period of time (Carter and Phillips, 1969; Carter and Rahe, 1975), heritability levels of somatotype have also been suggested to be moderate (Bouchard and Lortie, 1984) to high (Parnell, 1958; Peeters *et al.,* 2007). This would suggest that whilst somatotype could be altered in an untrained population, there may be a limit to the magnitude of that change, particularly in more athletic population groups. Once a somatotype is established, it may take an extended period of time to change that somatotype and even then changes may be limited. This may limit a person's ability to be successful in certain sporting pursuits.

Elements of body composition, such as somatotype, have also been identified as being genetically mediated (Parnell, 1958; Orczykowska-Swiatkowska *et al.*, 1978; Chovanova *et al.*, 1982; Bouchard and Lortie, 1984; Orczykowska-Swiatkowska *et al.*, 1988; Peeters *et al.*, 2003; see Chapter 2 for more detail). This shares a commonality with reponses to training, where in the past 30 years it has been suggested that individual responses to training may be dictated by genes (Bouchard, 1983; Pescatello *et al.*, 2006).

Responses to training are determined by various factors, including the magnitude of the training load (Sale, 1987; Fleck and Kraemer, 2014) and volume (Kraemer *et al.,* 1993; Kraemer *et al.*, 1995), type of exercise (Dudley *et al.*, 1991; Durand *et al.*, 2003), training experience (Ahtiainen *et al.*, 2004; Tremblay *et al.*, 2004), sex, and age of the participants. Some of these factors have resulted in large inter-individual acute and chronic responses to training, including changes in muscle mass/size (Phillips *et al.*, 2013; Ahtiainen *et al.*, 2016) and strength (Erskine *et al.*, 2010; Ahtiainen *et al.*, 2016); hormonal responses (Dudley *et al.*, 1991; Durand *et al.*, 2003); changes in maximal oxygen update ($\dot{V}O_{2max}$) (Buchheit *et al.*, 2010; Astorino and Schubert, 2014); exercise heart rate (Scharberg-Rosenberger *et al.*, 2012); fuel metabolism (Despres *et al.,* 1984; Savard *et al.,* 1985); and cardiovascular risk factors, such as resting systolic blood pressure (SBP), and in fasting plasma high-density lipoprotein-cholesterol (HDL-C), triglycerides (TG), and insulin (FI) (Bouchard *et al.,* 2012). Even when the factors affecting responses to training have been largely controlled, there is still a marked heterogeneity in the response to training (Hartman *et al.,* 2007). Researchers have attempted to demonstrate thresholds for certain responses to training; where individuals experience marked responses to training they are referred to as 'responders', whilst those who show little or no responses are termed 'non-responders' (Mann *et al.*, 2014).

Investigations of monozygotic (MZ) twins show strong correlations between genes and trainability, with pairs of MZ twins demonstrating similar responses to training compared to brothers or sisters (Despres and Bouchard, 1984; Prud'homme *et al.,* 1984; Hamel *et al.,* 1986; Bouchard et al., 1992). The finding of a heritability of training response has resulted in the discovery that certain genes have some influence over the responses to different types of training (Clarkson *et al.,* 2005; Pescatello *et al.,* 2006; Davidsen *et al.,* 2011). For example, there is a link between the angiotensin-I converting enzyme (ACE) D allele and hypertrophy of cardiac muscle following physical training (Montgomery *et al.,* 1997), that could influence endurance performance (Gayagay *et al.,* 1998; Woods *et al.,* 2001). It would seem that people are predisposed to respond to training in a certain way as a result of their genes, and that in order to maximise the physiological adaptation to exercise, training prescription should take this into account.

Developments in the recent somatotype research focus on links between somatotype variables and responses to exercise training (Chaouachi *et al.,* 2005; Marta *et al.,* 2013; Saha, 2014). Given the common link that somatotype and training response has to heritability, this suggests a new direction for somatotype research. To date, this research has predominantly focused on youth and adolescent populations (Marta *et al.,* 2013; Saha, 2014) or aerobic training methods (Chaouachi *et al.,* 2005). Despite this, mesomorphy in particular has shown strong links to strength and power-based performance in athletic populations (Pilis *et al.,* 1997; Quarrie and Wilson, 2000; Lewandowska *et al.,* 2011). However, given the prior training experience of these populations and the potential influence of this training on somatotype rating, it would seem prudent to attempt to establish the relationship between somatotype and acute and chronic responses to resistance exercise in the untrained population.

1.1 Research Context

The investigations described in this thesis, therefore, seek to identify whether somatotype influences acute and chronic responses to resistance exercise in the untrained population. The first study (Chapter 3) will look to establish the relationship between anaerobic variables (particularly strength) and somatotype components in the untrained population to establish if this relationship is similar to that seen in the athletic population. Chapter 4 will look to establish reliability in somatotype grouping according to dominant somatotype component, and to also establish reliability in measures of muscle architecture via B-Mode ultrasound. Following this, a further empirical study (Chapter 5) will establish if there are any differences in the way that somatotype groups present

muscle architecture measures and acute salivary hormone responses to resistance exercise. Finally, Chapter 6 will investigate whether there are any differences between somatotype groups in response to chronic resistance exercise.

Chapter 2: Review of the Literature

2.1 Overview of somatotyping

The phenotype or visual appearance of a person is the result of the interaction between genes and the environment and is often referred to as physique (Carter and Stewart, 2012). A summary of a person's overall physique is often given using somatotype, a method originally developed in the 1940s by Sheldon, Stevens and Tucker (1940). The somatotype is the human body's present shape and composition numerically represented. A somatotype rating gives the classification of physique by using measures relating to body shape and composition independent of body size, assessing adiposity (fatness), musculo-skeletal robustness, and linearity (Carter *et al.*, 1983; Carter and Heath, 1990; Carter, 2002a). A person's somatotype is identified by assigning them a three-numeral rating, indicating the size of each component element (endomorphy, mesomorphy, ectomorphy; Figure 1.1) (Carter, 2002a; Carter and Stewart, 2012). Carter and Heath (1990) developed a rating system for each component to further describe the somatotype in qualitative detail (Table 2.1). Somatotype values have been observed up to and over 16 for endomorphy, up to and over 12 for mesomorphy, and up to and over 9 for ectomorphy (Carter and Stewart, 2012). Theoretically, Heath-Carter somatotype ratings have no upper limit. Since the somatotype is a three-numerical representation of physique it is considered a summary of attributes (Carter *et al.,* 1983). In short, the somatotype gives a present holistic quantification of the morphology and characteristics of the human body (Monyeki *et al.,* 2002; Yavuz, 2013).

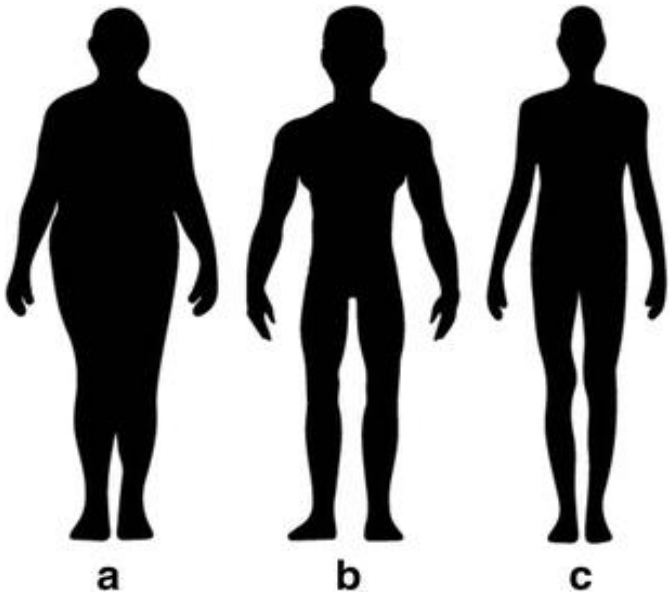


Figure 2.1: Visual representation of a.) endomorph; b.) mesomorph; c.) ectomorph *(Modified from Schwartz et al., 2017)*

Table 2.1*:* Within-component rating system for individual somatotype components

Numerical somatotype rating (AU)	Descriptive rating
0.5-2.5	Low
3-5	Moderate
5.5-7	High
7.2 and above	Very high

Adapted from Carter and Heath (1990); Carter and Stewart (2012)

AU = Arbitrary Units. N.B. there is no theoretical upper limit to these ratings

Each of the three numerical components relates to a different aspect of physique. The endomorphic component of somatotype represents the economy of the digestive system to determine the size and location of adiposity (Willgoose and Rogers, 1949). Endomorphy ratings increase with increases in adipose tissue deposition (Withers *et al.,* 1986; Carter and Heath, 1990). High mesomorphic ratings demonstrate strong musculo-skeletal development (Carter and Heath, 1990). Whilst not solely relating to muscle mass (skeletal robustness is also important), it is intuitive that those with larger muscle mass normally rate more highly in terms of mesomorphy (Withers *et al.,* 1986). Ectomorphy quantifies the relative linearity or slenderness of a person's physique (Carter, 1996).

The categorisation of a person in terms of somatotype is done according to the dominant number in the three numeral rating. Simple categorisation involves the three dominant somatotypes and a fourth category of "central" (see table 2.2 for detailed description; Carter, 2002a). A more detailed categorisation can occur to demonstrate similarity of component dominance with a somatotype rating (Table 2.3; Carter, 2002a). Simple and detailed categorisation can be visually represented on a somatochart, which is a two-dimensional plot of the three-numeral somatotype (Carter, 2002a). The coordinates for a somatopoint (the plot of a somatotype) are calculated as follows:

$$X = \text{ectomorphy} - \text{endomorphy}$$

$$Y = 2 \times \text{mesomorphy} - (\text{endomorphy} + \text{ectomorphy})$$

The somatochart can be used to identify the somatotype dominance and demonstrate distribution of somatotypes in group data (Figure 2.2; Carter and Heath, 1990).

Table 2.2: Simple somatotype categories

Category	Description
Central	No component differs by more than one unit from the other two.
Endomorph	Endomorphy is dominant, mesomorphy and ectomorphy are more than one half unit lower.
Mesomorph	Mesomorphy is dominant, endomorphy and ectomorphy are more than one half unit lower.
Ectomorph	Ectomorphy is dominant, endomorphy and mesomorphy are more than one half unit lower.

(Carter, 2002a)

Table 2.3: Detailed somatotype categories

Category	Description
Central	No component differs by more than one unit from the other two, and consists of ratings of 2, 3 or 4.
Ectomorphic endomorph	Endomorphy is dominant and ectomorphy is greater than mesomorphy
Balanced endomorph	Endomorphy is dominant and mesomorphy and ectomorphy are equal (do not differ by more than one-half unit).
Mesomorphic endomorph	Endomorphy is dominant and mesomorphy is greater than ectomorphy.
Mesomorph-endomorph	Endomorphy and mesomorphy are equal (do not differ by more than one-half unit), and ectomorphy is smaller.
Endomorphic mesomorph	Mesomorphy is dominant and endomorphy is greater than ectomorphy.
Balanced mesomorphy	Mesomorphy is dominant and endomorphy and ectomorphy are equal (do not differ by more than one-half unit).
Ectomorphic mesomorphy	Mesomorphy is dominant and ectomorphy is greater than endomorphy.
Mesomorph-ectomorph	Mesomorphy and ectomorphy are equal (do not differ by more than one-half unit), and ectomorphy is smaller.
Mesomorphic ectomorph	Ectomorphy is dominant and mesomorphy is greater than ednomorphy
Balanced ectomorph	Ectomorphy is dominant; endomorphy and mesomorphy are equal and lower (or do not differ by more than one-half unit).
Endomorphic ectomorph	Ectomorphy is dominant and endomorphy is greater than mesomorphy.
Endomorph-ectomorph	Endomorphy and ectomorphy are equal (or do not differ by more than one-half unit), and mesomorphy is lower.

(Adapted from Carter and Heath, 1990; Carter, 2002a)

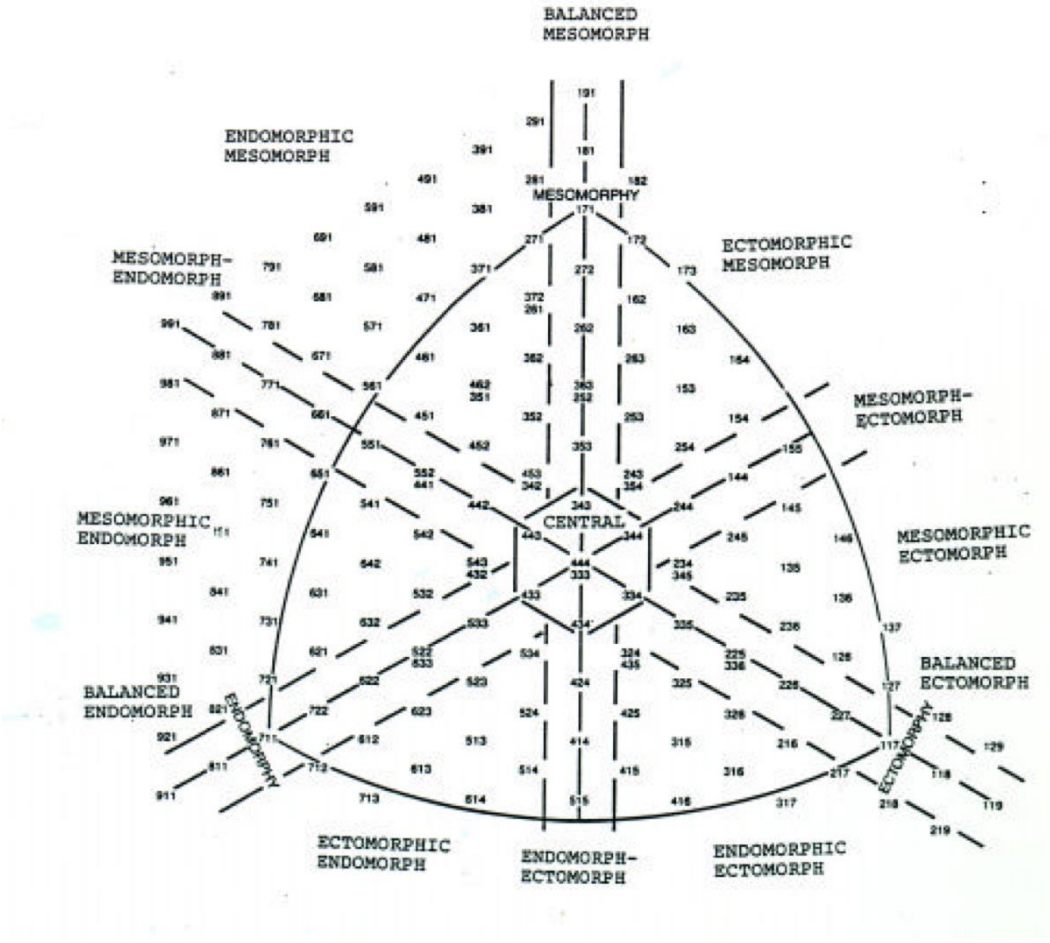


Figure 2.2: Somatochart demonstrating the location of the detailed somatotype ratings on a two-dimensional plot.

2.2 Somatotype data analysis

Somatotype numbers can be presented and analysed in several ways. The group mean of each somatotype component gives a measure of central tendency for the sample (Carter and Heath, 1990). This would also allow for somatotype categorisation of the sample mean (Carter, 2002a). The scatter of somatotype values around the group mean is also of interest when analysing the nature of the sample (Carter and Heath, 1990). The somatotype attitudinal distance (SAD) is the three-dimensional distance between any two somatopoints in component units (Duquet and Carter, 2009). The SAD gives an indication of how similar two somatotypes are, with a smaller value representing similar somatotypes (Carter *et al.,* 1983). The somatotype attitudinal mean (SAM) is the mean of the SADs of each somatopoint from the mean somatopoint of the sample (Duquet and Hebbelinck, 1977), and thus gives an indication of the homogeneity of the sample from which it is derived (Carter *et al.,* 1983). Thresholds for SAM have previously been set by Carter *et al.* (1997) as >1.0 being large, 0.8-0.99 medium and <0.79 as small. The migratory distance (MD) of a somatotype can be used to indicate the

distance and direction of change over time (Carter and Heath, 1990), and is calculated by adding together the SADs between a series of somatotypes obtained over time and expressed in component units (Carter *et al.,* 1983). These statistics give additional descriptive information about the nature of a study sample that cannot be displayed when simply providing the mean somatotype of the group.

2.3 Somatotype measurement

The original Heath-Carter method of somatotyping combines the methods of anthropometry and photoscopy (Carter, 2002b). As the photoscopy method is now largely obsolete, much of the recent literature in somatotype research utilises just the anthopometric method (Barbieri *et al.,* 2012; Busko *et al.*, 2013; Ferrari *et al.,* 2013; Ahvazi *et al.*, 2014; Grgantov *et al.,* 2017).

There are ten measurements of anthropometric dimensions required in order to calculate somatotype. These are stretch stature, body mass, triceps skinfold, subscapular skinfold, supraspinale skinfold, medial calf skinfold, biepicondylar humerus and biepicondylar femur, arm girth flexed and tensed and maximal calf girth (Carter, 2002b). Full protocols for establishing the locations of these measures are given in the International Society for the Advancement of Kinanthropometry (ISAK) anthropometric handbook (Esparza-Ros *et al.,* 2019). Double measures are taken per dimension, and if the two measures differ considerably then a third measure is taken. Where two measures are taken the mean is utilised, whilst the median is used for three measures (Esparza-Ros *et al.,* 2019).

2.4 Somatotype and body composition

Somatotyping is often seen as preferable to other typical measures of body composition as it is able to differentiate between those who might share a similar body mass index (BMI) or percentage body fat (Duquet and Carter, 2009). Bolunchuk and colleagues (1989) also attest that somatotyping identifies the morphological characteristics of body structure and not body composition. Despite this, in a study containing 422 heterogeneous adults (all ages and fitness levels, approximately equally split males and females), the previous authors found that the endomorphic component of somatotype was highly positively correlated with skinfolds (R^2 = 97%), and the mesomorphic component had a lower positive correlation with skinfolds and a higher positive correlation with bone and muscle (R^2 = 99%) as measured with hydrodensitometry. This indicates that components of somatotype have a direct relationship with elements of body composition. Ectomorphy has been

shown to have a negative correlation with skinfold, bone and muscle measurements and positive one with standing height, demonstrating a clear independence of the somatotype parameters to represent different aspects of physique (Bolunchuk *et al.*, 1989). In a study on 43 primary and high school girls, Allard *et al.* (2001) demonstrated a 9.3% smaller calf girth in ectomorphic participants compared to endomorphic, indicating a clear difference in the muscle mass of those dominant in ectomorphy. In a study of 1410 individuals across a range of ages and from both sexes, positive correlations were observed between sum of 6 skinfolds and endomorphy (age group ranges: 0.94-0.98) and mesomorphy (age group ranges: 0.41-0.53), and negative with ectomorphy (age group ranges: -0.64 - -0.71) (Katzmarzyk *et al.,* 1999). Whilst this indicates that skinfolds do relate to each component of somatotype, it also suggests this relationship is different with each component and so re-affirms their ability to represent a different aspect of physique.

2.5 Somatotype and genes

There is considerable variation in somatotype components amongst the general population (Carter and Heath, 1990) likely determined by a combination of genetic and environmental factors (Peeters *et al.,* 2007). Environmental factors such as nutrition, physical activity and disease have been reported to impact upon physique changes (Carter and Heath, 1990; Malina and Bouchard, 1991; de Ridder *et al.,* 2016; Schwingshakl *et al.,* 2016; Mario *et al.*, 2017). Despite this, certain anthropometric variables are strongly associated with genes such as bone breadth and stretch stature (Rankinen *et al.,* 2006). Studies that have investigated twins have established that all three somatotype components have heritability estimates that are moderate to high (Parnell, 1958; Orczykowska-Swiatkowska *et al.*, 1978; Chovanova *et al.,* 1982; Bouchard and Lortie, 1984; Orczykowska-Swiatkowska *et al.,* 1988; Song *et al.,* 1994; Peeters *et al.,* 2003), indicating a strong genetic component. In particular, mesomorphy (84.6%) and ectomorphy (66.5%) are estimated to be strongly heritable (Peeters *et al.,* 2007). The latter authors also indicated that endomorphy (28.0%) does have some element of heritability but is likely mediated more by environmental factors such as diet and physical activity. Despite these findings, in a study of 63 men Bolunchuk *et al.* (2000) observed no significant differences in energy and macronutrient intake between somatotype groups. However, these authors only looked at acute exercise function and did not monitor physical activity over any time period. A person's participation in physical activity over time could be another mediating factor in somatotype component magnitude. It is also possible that metabolic (and therefore physiologic) processes could influence somatotype, rather than nutritional intake per se. The contribution of fat tissue to the endomorphic rating makes this component particularly susceptible to environmental variation (Peeters *et al.,* 2007). When the effects of seven

socioeconomic indicators were controlled for in a study of 239 French-Canadian families, a higher endomorphic heritability rating of 50% was found (Bouchard *et al.,* 1980). In a further family study, Katzmarzyk and colleagues (2000) indicated the influence of genes on ectomorphy and mesomorphy components by demonstrating significant parent-child and sibling correlations in these components, but no such relationship in spouses. Overall, heritability observations indicate that whilst elements of somatotype could be altered by environmental factors, there may be a limit to the magnitude of that change.

Athlete selection in sports disciplines generally focuses on parameters that will contribute to successful performance, and genes may have an influence over many of these factors (Lewandowska *et al.,* 2011). Research indicates somatotype has a genetic element and so may be an important factor to consider when selecting for sporting success.

2.6 Somatotype and performance

The majority of somatotype studies in the literature have examined the relationship between physique and successful performance in a wide variety of sports. Many studies have identified that somatotype components are highly related to performance in sports such as combat sports (Lewandowska *et al.*, 2011), gymnastics (Claessens *et al.*, 1999), modern pentathlon (Claessens *et al.,* 1994), rowing (Rodriguez, 1986; Slater *et al.,* 2005), rugby union (Olds, 2001), swimming (Siders *et al.,* 1993) weight-lifting (Carter, 1970) and endurance and ultra-endurance events including distance running (Bale *et al.*, 1986; Berg *et al.*, 1998) and Ironman (Kandel *et al.*, 2014). Elite level athletes in any particular sport often demonstrate similarity in morphology, and particularly somatotype (Bale *et al.,* 1986; Lewandowska *et al.,* 2011). However, it is generally not understood whether training for those sports brings about physical changes, or whether individuals with existing morphological traits become most successful if they enter those sports. Given that some authors have indicated training (Tanner, 1964; Can *et al.*, 2004), and others have pointed towards genetics (Jokl, 1964; Medved, 1966; Micheb, 1967) it is likely a combination of both. However, given the strength of heritability of somatotype components suggested by Peeters *et al*. (2007), and the suggestion by many that somatotype and performance are related it would seem sensible to attempt to establish a clear understanding of the relation between somatotype and aspects of performance. Some studies have even gone as far to suggest that somatotype itself accounts for up to 60% of the variance in physical fitness tests in adult sportsmen (Stepnicka, 1974; Stepnicka, 1986) further strengthening the somatotype-performance observation.

The three ratings that form a somatotype (see section 2.1) relate to very specific aspects of body structure and composition such that they naturally associate with certain aspects of physiology. For example, in endomorphs the body's economy is dominated by the digestive system to determine the size and location of adiposity (Willgoose and Rogers, 1949). Studies clearly show that endomorphy is positively related to subcutaneous adipose tissue measured via skinfolds (Bolunchuk *et al.*, 1989; Katzmarzyk *et al.*, 1999). Research has further related the predominance of adipose tissue in endomorphy with muscular weakness (Ackland, 2008). In rowing, endomorphy has been shown to hinder performance (Rodriguez, 1986; Slater *et al.,* 2005). Two assessments of somatotypes using the early Sheldon method demonstrated performance and endomorphy were negatively related (Willgoose and Rogers, 1949; Malina, 1975). Although this study utilised a method of somatotype analysis that is now largely defunct, it still clearly demonstrated the impact of excess adipose tissue on performance. Endomorphy ratings increase with accrual of adipose tissue deposition (Withers *et al.*, 1986; Carter and Heath, 1990). Research has demonstrated that excessive measures of body fat impede fast bodily movements required in performance aspects such as agility (Sharkey, 1997) and add excess metabolic burden (Withers *et al.*, 1986; Norton *et al.*, 1996). Reduced fat mass is further associated with enhanced acceleration when horizontally or vertically projecting the body (Withers *et al.,* 1986). Increased fat mass has detrimental effects on performance, affecting energy requirements and power-to-body mass ratio (Norton *et al.,* 1996). In their study on mountain climbers, Barbieri *et al.* (2012) emphasised the importance of low endomorphism in optimising the strength-to-mass ratio that positively determined performance in climbing based events. Further, in a study assessing 312 prepubescent children Marta and colleagues (2011) found that somatotype significantly determined performance in strength tests, and to a greater degree than percentage body fat. Endomorphy was positively related to some aspects of strength performance but was a limiting factor in body propulsion and lifting tasks. Malina and Bouchard (1991) purported that negative relationships between endomorphy and most motor tasks are likely related to the higher impact of absolute as opposed relative lean body mass on such tasks.

Research has demonstrated further influences of excess adipose tissue on particularly physiological variables. For example, Lazarus *et al.* (1998) demonstrated a significant negative association between forced vital capacity (FVC) and percent body fat in 621 healthy male adults. The sheer number of participants in this study combined with the adjustment of FVC for lifestyle factors such as smoking habits and bronchial conditions contribute to the strength of this finding. The authors' explanation of the findings was incomplete, although there was a suggestion that ventilator function may have been

mechanically limited by fat deposits. Limitations in ventilation will impact the ability to inhale oxygen to utilise during aerobic metabolism, and inhibit the ability to exhale waste products resulting in premature fatigue (McArdle *et al.*, 2014). Any physiological limitations of this nature will naturally negatively impact upon performance, and these may offer some explanations as to why those athletes with lower endomorphic ratings perform better in sports requiring strong physiological profiles. Performance in endurance running (Knechtle *et al.*, 2010) and short-distance triathlon (Landers *et al.*, 2000) is strongly influenced by body fat measures, with a strong association between total race time and percent body fat in particular.

Successful athletes in many sports appear to have high mesomorphic ratings, demonstrating strong musculo-skeletal development (Carter and Heath, 1990; Barbieri *et al.,* 2012). Early research theorised that mesomorphy is inherently linked to strength and speed (Lauchbach and McConville, 1969). Whilst not solely relating to muscle mass (skeletal robustness is also important), it is intuitive that those with larger muscle mass normally rate more highly in terms of mesomorphy (Withers *et al.,* 1986). Larger muscles are stronger muscles (Komi, 1979; Draper and Marshall, 2013). Humans with larger muscle masses, therefore, are normally stronger individuals, and have better ability to exert that force in a powerful manner normally relating to better performance in certain events (Ergen *et al.*, 1985; Rodriguez, 1986; Can *et al*., 2004; Slater *et al.,* 2005). Correlations between mesomorphy and strength have been established in some dated research (Willgoose and Rogers, 1949; Laubach and McConville, 1969; Schreiber, 1973). Early research by Tanner (1964) established that power events were predominated by those with higher mesomorphy ratings. In a study of thirteen male judoists Lewandowska *et al.* (2011) established a strong significant positive correlation between mesomorphy and power output at different external loads. Whilst the study predominantly recruited those with mesomorphic somatotype ratings, and failed to take the impact of the other elements into account, it still adds strength to the observation of improved strength and power-based performances with higher mesomorphic ratings. Judo and other combat sports are predominantly power based. It has further been established that as the level of judo competition increases so does the mesomorphic value of those competing, whilst endomorphy decreases (Kuzmicki and Charzewski, 1987; Charzewski *et al.*, 1991; Fagerlund and Hakkinen, 1991).

Quarrie and Wilson (2000) demonstrated that mesomorphy was the predominant somatotype category to influence task specific force (i.e. in the scrum) in 56 semi-professional rugby union forwards. Although technique was still a predicting factor in the study, the authors demonstrated that

muscle mass does have the ability to influence performance in that specific task. The positive relationship between anaerobic power and lean body mass, and the negative one with body fat has further been established in Olympic weightlifters (Pilis *et al.*, 1997) and rowers (Rodriguez, 1986; Slater *et al.,* 2005). However, Ergen *et al.* (1985) found no correlation between maximal alactacid anaerobic power measured using the Margaria treadmill test and somatotype components in forty male fencers. The majority of participants in this study had high to moderate mesomorphy ratings, with very few extremes of the other two components. This could have influenced the outcome measures, since the negative influence of either component (but particularly endomorphy) could not be truly assessed. In fact, Bolonchuk *et al*. (2000) note this to be an issue with many somatotype papers, where extremes in any of the components are often absent preventing the full range of values from being assessed.

Ectomorphy quantifies the relative linearity or slenderness of a person's physique (Carter, 1996). It is less obvious with this category how body composition relates to performance variables, although someone with a higher ectomorphy score will often have a low endomorphy score. Early indications were that ectomorphy did not have a significant influence over physical fitness scores (Willgoose and Rogers, 1949). Low scores in ectomorphy can be advantageous in strength movements where short levers are preferential (Carter, 1970). This has further been validated by observations of negative correlations between power output and ectomorphy in judoists (Lewandowska *et al.,* 2011). Ectomorphs may also be disadvantaged in weight-bearing strength movements by a lower standing posture stability accounted for by smaller muscle mass, high height-to-weight ratio and a higher position of centre of mass (Allard *et al.,* 2001). This instability may influence an ectomorph's ability to apply strength and power in an optimal fashion when in a weight-bearing stance. However, the latter study did only demonstrate this finding in young (mean age 13.8 years) girls. When grouping children together, Lee and Lin (2007) demonstrated that it was the endomorphs that had the poorest stability, although their population of 709 children were slightly younger (9-11 years) than in the Allard *et al.* (2001) study. However, Keivan and Sadeghi (2019) tested 140 females across a range of 12-50 years and found a similar pattern to that in the Lee and Lin (2007) study. They concluded that joint stability and postural control are determined by muscle strength and structure, resulting in mesomorphs having the advantage with postural control.

Some authors have shown strong relationships between ectomorphy and positive aspects of performance. For example, in their study of 63 healthy males, Bolonchuk *et al.* (2000) demonstrated significant positive correlations between ectomorphy and heart rate, oxygen consumption, ventilator

rate and power output during a progressive cycle ergometer test. However, the magnitude of their dominant ectomorphy rating was only 3.9 so it is difficult to truly assess the scope of these relationships considering this value could go to 9 and beyond (Carter and Stewart, 2012). Ahvazi et al. (2014) demonstrated that the 24 dominant ectomorphs in their study had better range of motion and dynamic balance compared to the dominant endomorphs. The absence of a mesomorphy group in this study is an obvious limitation. Another observation with ectomorphs is their higher dependence on anaerobic glycolytic metabolism compared to participants dominant in endomorphy or mesomorphy (Schreiber, 1973; Bolunchuk *et al.,* 2000). In those studies in particular this reliance on glycolytic energy production was demonstrated through greater end exercise blood lactate concentration alongside a higher respiratory exchange ratio (RER) at peak exercise. However, these studies only used between group analyses of those with dominant somatotype ratings potentially overlooking the influence that the other ratings have upon the dominant one and excluding anyone not categorised in a dominant group from the analysis.

The combination of individual somatotype components has received some interest. Changes in one somatotype element have been demonstrated to result in changes in another in adolescents over time (Kandel *et al.*, 2014). Willgoose and Rogers (1949) observed the impact of one somatotype component on another in 153 University students with their observations closely related to performance in a Physical Fitness Index (PFI) test. They indicated that mesomorphs with an endomorphic components higher than 4 were likely to have lower strength and PFI scores than those with lower endomorphic components. They also observed that dominant ectomorphs with a moderate-high mesomorphy score had better performances on the PFI. However, of their 153 male participants, 104 were dominant mesomorphs potentially devaluing the impact of the results from the other two dominant groups. Further, the Sheldonian method of somatotype rating used in this study is often considered to be unreliable due to its use of photograph analysis rather than direct anthropometry and has not widely been utilised in research since the development of the Heath-Carter method (Carter and Heath, 1990).

Many studies have established the link between absolute and task specific strength or power and mesomorphy (Lauchbach and McConville, 1964; Malina and Bouchard, 1991; Lewandowska *et al*., 2011; Busko *et al.,* 2013; Saha, 2014). However, none of these studies investigate how the magnitude of the other ratings influence performance alongside mesomorphy. Ectomorphy and endomorphy have often been found to explain some of the variance in performance where body propulsion is important, such as in explosive leg power (Marta *et al.,* 2011; Busko *et al.,* 2013; Saha, 2014), the

association being a positive one with ectomorphy and a negative one with endomorphy. When a more detailed somatotype categorisation is used it is often the meso-ectomorphs that demonstrate superior motor task performance (Jaksic and Cvetkovic, 2009). In their ectomorphic school girls, Allard *et al.* (2001) demonstrated that this group had the poorest postural stability compared to the other two dominant groups, but that they were also statistically lowest in mesomorphy rating, suggesting being high in ectomorphy may only have negative consequences if it is also coupled with a low mesomorphy score. It is also often the case that better performing athletes, such as those in the top 4 teams at the 1994 Women's World Basketball Championships, possess higher values in both mesomorphy and ectomorphy than their lower performing opponents (Carter *et al.,* 2005), indicating the importance of both components to successful power-based sporting performance.

A critical point in relation to somatotype and performance lies in the observation that the majority of somatotype-performance associations exist in tests of predominantly physiological components of strength, endurance and speed. Those aspects of performance that are more strongly influenced by motor ability such as flexibility, balance and speed of limb movement are much less related to somatotype (Farmosi, 1980; Beunen *et al.,* 1985; Carter and Heath, 1990; Raudsepp and Jurimae, 1996). However, this gives further strength to establishing the physiological elements over which somatotype does have an influence and uncovering explanations for this influence. A comprehensive study should look to establish the multivariate relationships between somatotype as a whole rating and various physiological measures in a group of healthy participants.

2.7 Somatotype and training

A more recent shift in the research literature has started to examine the impact of somatotype on responses to various types of physical training. In 125 prepubescent children, Marta *et al.* (2013) showed that the endomorphic component reduced the magnitude of training-induced gains in vertical jump height, whilst the mesomorphy and ectomorphy components were positively related to gains in sprint speed. Although these findings were demonstrated in children, they do indicate a clear importance of somatotype components to training adaptations. Since somatotype components are considered genetically-stable from around 8 years old (Malina *et al.,* 2004), it is likely that the findings in Marta *et al.*'s (2013) 10-11 year olds are representative of genetic potential. Mesomorphy and gains in strength were not associated in the latter paper, but this is likely due to adaptations in neurological muscle function at this age as opposed to muscle growth (Ramsay *et al.,* 1990; Ozmum *et al.,* 1994). The training programme in the Marta *et al.* (2013) study consisted of 8-weeks of

plyometric-type exercises, thus targeting power and explosive movements rather than pure strength per se. It is not clear what impact these exercises had on body composition, specifically muscle mass since post-training values of body composition or somatotype are not presented.

In an early study by Schreiber (1973), 52 university athletes from a variety of sports were tested at baseline for anaerobic power using the Margaria-Kalamen test and then undertook 8 weeks of sport-specific conditioning. Those in the dominant mesomorph group were the only ones to significantly improve their anaerobic power following the conditioning period. All three somatotype groups increased their post-test lactate concentration after the training, but only the ectomorph group demonstrated a significant increase. However, only a random sample of 2 athletes from each sport (12 athletes) undertook the lactate testing reducing the power of the observations particularly with respect to the number of athletes in each somatotype group. The results from this study support the observation of an advantage to mesomorphs in gains in power over a training period, although this may be a consequence of the type of conditioning undertaken specific to the requirements of the individual sport.

Saha (2014) demonstrated that the relationship between somatotype components and explosive leg power measured using a Sergeant jump was similar regardless of athletic conditioning in 500 young college students, suggesting that the impact of somatotype on leg power does not change in the face of athletic training. This notion is supported by Marta *et al.*'s (2011) study where somatotype more significantly determined strength performance in 312 prepubescent children than physical activity levels. The influence of physical activity and exercise may be minimal on the relationship between somatotype and strength or power performance in particular.

Chaouachi and colleagues (2005) chose to investigate the influence of somatotype on aerobic capacity trainability in 41 North African physically active students. Grouping the participants according to their detailed somatotype (4 groups; endomorph-mesomorph, mesomorph, mesomorph-ectomorph and ectomorph), participants completed a 12-week aerobic training programme preceded and followed by a series of aerobic capacity tests. The mesomorph and meso-ectomorph groups demonstrated significantly greater improvements in aerobic capacity. The authors concluded that genetic factors may be important in explaining the observations seen, a view supported by early research by Bouchard and colleagues (1992) who indicated training variability to be partly explained by genetic factors.

Given that the combination of mesomorphy and ectomorphy already appears to offer superior ability to adapt to strength performance, it may be that these components of somatotype are the most important in determining overall athletic performance. However, the narrow range of detailed somatotype groups utilised by Chaouachi *et al.* (2005) results in unknown comparisons with, for example, endomorphs and ectomorph-endomorphs.

The nature of somatotype adaptation during training has generally received little attention. Body composition across a sporting season has been documented and demonstrated somatotype components to be relatively stable (Casajus, 2001). When testing 15 male football (soccer) players from La Liga during the competition phase, Casajus (2001) demonstrated that there was no significant difference in somatotype components over a 6-month period, despite a significant decrease in sum of 6 skinfolds. There was a mean drop in endomorphy of 0.2 units during the second testing session, but given this is similar to the magnitude of measurement error demonstrated in other somatotype studies, it is unlikely to demonstrate any significant alteration. Not only does this reaffirm the ability for somatotype to give additional information to simple skinfold measures, but it also suggests there is a relative stability to somatotype over a long period of physical activity and conditioning.

2.8 The influence of sex on somatotype and performance

There appears to be a marked difference in the expression of somatotype between males and females. In young participants without sexual dimorphism, boys tend to be more mesomorphic and less endomorphic than girls (Malina and Bouchard, 1991; Sanchez-Andres, 1995; Katzmarzyk *et al.,* 1999). A similar relationship has been found in adolescents and adults (Gordon *et al.,* 1985; Song *et al.,* 1994; Katzmarzyk *et al.,* 1999). In adults, these differences are attributed to the action of sex steroid hormones, whereas in prepubescence the observations have no obvious explanation (Wells, 2007). Regardless, it is evident that the manifestation of somatotype variation differs between the male and female population.

In exploring the contribution of genes and environmental factors to somatotype, Peeters *et al.* (2007) found that males and females were similar in those factors, but that the relative and absolute contribution of each factor to somatotype variation was significantly different between them. Song *et al.* (1994) also found that the 3 somatotype components are more closely related in males than in females. Given this, it is sensible that male and females should be investigated separately when

looking at associations between somatotype and physiological factors. This view is supported by Momirovic *et al.* (2003), who indicated that consistency in age and sex are vital to ensure correct definition of somatotype components.

In associating body composition to somatotype components, Bolunchuk *et al.* (1989) found that fat free weight measured by hydrodensitometry was positively associated with mesomorphy and negatively associated with ectomorphy in male participants only. The relationship did not exist amongst female participants. However, on average their female participants were much more endomorphic and much less mesomorphic than their male counterparts. It is not obvious how these relationships might change if male and female participants were matched on somatotype component ratings.

Many of the associations between physiological function and somatotype components also appear to differ between males and females. For example, Tanner *et al.* (1960) and Gordon *et al.,* (1987) demonstrated that serum cholesterol was highest in endomorphs and lowest in ectomorphs in male participants only. The relationship between variables in female participants was relatively random in comparison to males. The predominance of mesomorphy in events of strength and power has been shown to be similar in male and female athletic populations (Can *et al.,* 2004), whilst others have shown wider distribution of somatotypes in female athletes (Sands *et al.,* 2005) with endomorphic ratings often being higher in female sport participants (Gualdi-Russo and Graziani, 1993).

2.9 Conclusions of the literature review

Somatotype is a relatively straight-forward and accessible method for assessing physique. Somatotype relates to body composition but also represents the constitutional whole in a more comprehensive manner than body composition measures can. Genes appear to have an influence on somatotype and this could result in differences in the manifestation of training responses.

Mesomorphy and ectomorphy are most regularly associated with strength and power performance. Endomorphy appears to have a negative impact, particularly when translocation of mass is involved. This mesomorphy and ectomorphy advantage in performance also appears to follow into the limited training research that has been done to date. There is, however, a lack of research specifically

targeting the impact of periodised strength training on adults from different somatotype groups. Males and females have largely different mean somatotypes, and the way these somatotype components are influenced by the environment and therefore manifest in performance/training outcomes is different between males and females so they should be study as separate populations.

Chapter 3: Study 1. The relationship between somatotype and anaerobic performance.

3.1 Abstract

The link between athlete physique and performance in sports is well established. However, a direct link between somatotype three-numeral rating and anaerobic aspects of physiological performance has not yet been reported. The purpose of this study was to assess the relationship between somatotype and anaerobic performance variables. Thirty-six untrained males (mean [SD] 26.0 [9.8] y; 79.5 [12.9] kg; 1.82 [0.07] m) were somatotype-rated using the Heath-Carter method. Participants were assessed for three repetition maximum (3 RM) chest press and back squat and completed a 30-second maximal sprint cycle test. For mesomorphy there were significant positive correlations with 3 RM chest press ($r = 0.56$, $p < 0.001$), and 3RM back squat ($r = 0.55$, $p < 0.001$). For ectomorphy there were non-significant negative correlations with 3 RM chest press ($r = -0.38$, $p > 0.017$), and 3 RM back squat ($r = -0.34$, $p > 0.017$). Individual regression analysis indicated mesomorphy was the best predictor of 3 RM chest press performance, with 31.4% of variance in performance accounted for by the mesomorphy rating ($R2 = 0.31$, $p < 0.01$). A combination of mesomorphy and ectomorphy best predicted 3 RM back squat performance ($R2 = 0.39$, $p < 0.05$). The study findings have demonstrated that approximately one third of strength performance is predicted by somatotype-assessed physique in untrained males. This could have important implications for the identification of those pre-disposed to perform well in sports containing strength-based movements and prescription of training programmes.

3.2 Introduction

A somatotype rating gives a categorisation of physique by using measures relating to body shape and composition, assessing adiposity (fatness), musculo-skeletal robustness, and linearity or slenderness. Somatotype "expresses genetic determinism, observed from the morpho-constitutional point of view" (Malina and Bouchard, 1991, p. 92) and can be identified by assigning a three-numeral rating representing endomorphy, mesomorphy and ectomorphy (Carter and Stewart, 2012). In short, the somatotype gives a holistic quantification of the morphology and characteristics of the human body (Tanner, 1964).

It is generally not understood whether training for sports brings about physical changes (Stepnicka, 1986), or whether individuals with existing morphological traits become most successful if they enter specific sports (Medved, 1966). It may even be a combination of both factors and may be a result of bi-directional relationships between genetics and the environment, as suggested by Gottlieb's (2007) theory of probabilistic epigenesis. Given the strength of heritability of somatotype components suggested by Peeters *et al.* (2007) and the suggestion by many that somatotype and performance are related, it is necessary to establish the relation between somatotype and aspects of performance in a more comprehensive manner. The suggestion that somatotype itself accounts for up to 65% of the variance in physical fitness tests in adult sportsmen (Lauchbach and McConville, 1969) further strengthens the somatotype-performance observation. Authors have recognised the potential application of somatotype analysis to identify talented performers and in the design of training programmes (Busko *et al.,* 2013).

Much of the research identifies somatotype components as separate factors. For example, successful athletes in many sports appear to have high mesomorphy ratings, demonstrating strong musculo-skeletal development (Carter and Heath, 1990). In general, larger muscles are able to produce higher strength outputs (Draper and Marshall, 2013), which can lead to superior anaerobic performance. Many studies have established the link between absolute and task specific strength or power and mesomorphy (Lauchbach and McConville, 1964; Malina and Bouchard, 1991; Lewandowska *et al.,* 2011; Busko *et al.,* 2013; Saha, 2014). However, none of these studies investigate how the magnitude of the other ratings influence performance alongside mesomorphy, ectomorphy and endomorphy have often been found to explain some of the variance in performance where body propulsion is important, such as in explosive leg power (Marta *et al.,* 2011; Busko *et al.,* 2013; Saha, 2014), the association being a positive one with ectomorphy and a negative

one with endomorphy. However, low scores in ectomorphy can be advantageous in strength movements where short levers are preferable (Carter, 1970).

Changes in one somatotype element have been demonstrated to result in changes in another in adolescents over time (Kandel *et al.*, 2014). Willgoose and Rogers (1949) observed relationships between somatotype components in 153 University students. They indicated that mesomorphs with higher endomorphic components were likely to have lower strength and physical fitness index scores than those with lower endomorphic components. Song *et al.* (1994) and Peeters *et al.* (2007) observed that the three somatotype components share genes and environmental factors that contribute to more than 70% of the total variance of each component. They therefore concluded that somatotype should be subject to multivariate analysis rather than separate component analysis.

A critical point in relation to somatotype and performance lies in the observation that the majority of associations exist in tests of predominantly physiological components of strength, endurance and speed. Those aspects of performance that are more strongly influenced by motor ability such as flexibility, balance and speed of limb movement are much less related to somatotype (Farmosi, 1980; Beunen *et al.,* 1985; Carter and Heath, 1990; Raudsepp and Jurimae, 1996). However, this gives further strength to increasing knowledge and understanding by investigating relations between physiological elements and somatotype. A comprehensive study should look to establish the relationships between somatotype components and various physiological measures in a group of healthy adult participants.

The aim of this study, therefore, was to assess the relations between components of somatotype and measures of anaerobic performance. As previous research has largely focused on analysing single components, this study will explore whether multivariate analyses provide added value beyond single component analyses. It was hypothesised that there would be a significant relation between components of somatotype and aenaerobic performance, and that multivariate components will significantly explain a proportion of the variance in anaerobic performance.

3.3 Methods

3.3.1 Participants

Thirty-six physically active but untrained males (mean [SD] 26.0 [9.8] y; 79.5 [12.9] kg; 1.82 [0.07] m) were recruited to the study. The study received approval from the Faculty Ethics Committee (Appendix 1b). All participants were provided with an information sheet and consent form, detailing the purpose of the study and their right to withdraw at any time without any disadvantage of any kind, prior to the start of testing. As such, participants provided written informed consent to participate in the study (Appendix 1c and 1d).

3.3.2 Research Design

The research study adopted a quantitative correlational approach using primary data collection. Participants were recruited initially using purposive sampling for the initial body composition assessment, with the requirement that they be untrained (no planned and structured exercise programme undertaken or in the last 6 months but could still be physically active). Participants completed all experimental procedures in the same order. A priori sample size calculation (G* Power 3.1.9.6, Heinrich-Heine-Universität, Düsseldorf) was used to determine the participant number required. Utilising Cohen's (1988) guidelines for multiple regression effect size f^2 as 0.35 for a large effect, and including the 3 independent somatotype values as predictor variables a sample size of 36 participants was determined as appropriate for a calculated power of 0.81.

3.3.3 Procedures

Participants' anthropometric profiles were measured by a Level 3 ISAK anthropometrist, using ISAK protocols (Stewart *et al.*, 2011). Those anthropometric measurements required for somatotype calculations, and the calculations are outlined in section 3.3.4 below. As recommended by ISAK, multiple measures were recorded for each anthropometric variable and used to calculate intra-tester technical error of measurement (TEM) and intra-class correlation coefficients (ICC) (see Chapter 4 for more detail). Mean TEM for skinfolds was 2.12% and for all other measures (stature, body mass, girths and bone breadths) was 0.16%. ICC was 1.00 for all measures. Data from the anthropometric assessments were used to calculate somatotype using the Heath-Carter anthropometric somatotype equations (Heath and Carter, 1967).

On separate occasions, with a minimum 48-hour period between assessments, participants completed exercise tests assessing different aspects of anaerobic performance. All tests were performed in the same order for each participant: strength and anaerobic.

3.3.4 Somatotype assessment

Ten measurements of anthropometric dimensions were taken in order to calculate somatotype. These were stretch stature, body mass, triceps skinfold, subscapular skinfold, supraspinale skinfold, medial calf skinfold, biepicondylar humerus and biepicondylar femur, arm girth flexed and tensed and maximal calf girth (Carter, 2002). The locations of these measures were established using the full protocols described in the ISAK anthropometric handbook (Stewart *et al.*, 2011). Stretch stature (Seca 213 stadiometer, Germany) and body mass (Seca Quadra 808 digital scales, Germany) were measured to the nearest 0.1 cm and 0.1 kg respectively. Skinfolds were measured using Harpenden calipers (Harpenden, HAB International, UK) to 0.1 mm accuracy, whilst circumference measures were made with a small metal anthropometry tape (Cescorf, Brazil) to the nearest 1.0 mm. Bone breadths were measured using metal bone calipers (Holtain, UK) to the nearest 1.0 mm.

The following equations from Carter (2002a) were used to calculate decimalised somatotype values for each individual participant.

Endomorphy = $-0.7182 + 0.1451 \times \Sigma SF - 0.00068 \times \Sigma SF^2 + 0.0000014 \times \Sigma SF^3$

where ΣSF = (sum of triceps, subscapular and supraspinale skinfolds) multiplied by (170.18/height in cm). This is known as height-corrected endomorphy.

Mesomorphy = 0.858 x humerus breadth + 0.601 x femur breadth + 0.188 x corrected arm girth + 0.161 x corrected calf girth – height x 0.131 + 4.5

where corrected arm girth is arm girth flexed and tensed minus triceps skinfold, and corrected calf girth is maximal calf girth minus medial calf skinfold.

In order to calculate ectomorphy, first the height-weight ratio (HWR) was calculated:

$$\frac{\text{stretch stature}}{\text{body mass}^3}$$

IF HWR ≥ 40.75 then:

Ectomorphy = 0.732 x HWR – 28.58

If HWR is less than 40.75 and greater than 38.25 then

Ectomorphy = 0.463 x HWR – 17.63

If HWR is equal to or less than 38.25 then

Ectomorphy = 0.1

3.3.5 Strength Assessment

Each participant completed a strength assessment to determine their 3-repetition maximum (3RM) for chest press and back squat. Due to the novice ability of the participants, they attended a familiarisation session to gain experience with the technique of each lift. Where participants were unable to master the correct technique or lacked confidence, they were invited to a further familiarisation session prior to the testing session. The 3RM testing followed guidelines provided by American College of Sports Medicine (2017) for 1RM testing but terminated when the participant could only complete 3 repetitions. Participants initially completed a 5-minute steady-paced cycle and a series of submaximal repetitions of both chest press and back squat in order to warm-up. An initial load was placed on the bar based upon the load lifted during the familiarisation session(s) and the participant was required to complete as many repetitions as possible with this load. Following a rest period of 3–5 minutes, the load was increased by 2.5–20 kg and the exercise repeated. When the participant could only complete 3 repetitions of that exercise the load on the bar was recorded as the 3RM. Where possible, final 3RM for each exercise was determined within 4 trials.

3.3.6 Anaerobic Power Assessment

Participants completed a 10-minute warm-up prior to the test (5 minutes at 100 W and 5 minutes at 60% of individual maximal aerobic power [MAP] measured during a previous session in a similar protocol to that outlined by Cooke [2009]) and had a capillary blood sample collected from the fingertip - for lactate concentration analysis (Biosen C-Line, EKF Diagnostics, Germany) - pre-test, immediately and 5-minutes post-test. The maximal sprint cycle test involved participants completing a maximum effort for 30 s on a cycle ergometer (Monark 894E Peak, Monark, Sweden) against a

resistance of 7.5% body mass (Logan *et al.*, 2000). Peak, mean, and minimum power output and time to peak power output were obtained from the computer software linked to the cycle ergometer (Monark ATS Software, Monark, Sweden). Fatigue index was calculated as a percentage using the drop in power output post peak divided by the peak power output and multiplied by one hundred, as follows:

$$\text{Fatigue Index (\%)} = \left(\frac{\text{Peak power (W)- Minimum Power (W)}}{\text{Peak Power}}\right) \text{x } 100$$

3.3.7 Statistical Analysis

Somatotype attitudinal distances (SADs) were calculated for each individual somatotype compared to the overall group mean somatotype, using the method outlined in Chapter 2 (review of the literature [ROL]). The somatotype attitudinal mean (SAM) was calculated as the mean of the SADs and compared to the thresholds expressed by Carter *et al*. (1997; see Chapter 2: ROL) to indicate homogeneity of the sample.

All data were checked for normal distribution using skewness and kurtosis z-scores and the Kolmogorov-Smirnov test of normality. All data were found to be normally distributed ($p > 0.05$). A Pearson correlation coefficient analysis (r) was completed to compare somatotype ratings for endomorphy, mesomorphy and ectomorphy with the various measures from the performance tests and assessed using Cohen's (1988) correlation thresholds of 0.1 (small), 0.3 (medium) and 0.5 (large). To account for multiple comparisons and the chance of a type I error, a Bonferroni correction was applied to the p value (divided by 3 to acknowledge the 3 somatotype rating scores) such that this was set at $p < 0.017$. Following this, forced-entry regression analysis was completed for each dependent strength variable using the relevant somatotype categories as predictors. All statistical analysis was carried out using IBM SPSS for Windows (Version 22).

3.4 Results

Descriptive statistics of dependent and independent variables are provided in Table 3.1. Mean (± standard deviation) somatotype for the group was: endomorphy 3.4 (± 1.8), mesomorphy 4.5 (± 1.5), ectomorphy 2.6 (± 1.6). Individual somatotype values ranged from 1.2–8.3 (endomorphy), 0.7–8.7 (mesomorphy), and 0.1–7.1 (ectomorphy). SADs ranged from 0.7-6.9 and SAM was 2.4 somatotype component units. Figure 3.1 demonstrates the spread of somatotypes of the study participants on a somatochart.

Table 3.1: Mean anthropometric and performance data for study participants

Measure	Mean	Standard Deviation
Height (m)	1.82	0.07
Body Mass (kg)	79.5	12.9
Endomorphy	3.4	1.8
Mesomorphy	4.5	1.5
Ectomorphy	2.6	1.6
3RM Chest Press (kg)	61.0	18.1
3RM Back Squat (kg)	89.6	27.5
Peak Power Output (W)	1014.6	196.8
Mean Power Output (W)	690.3	105.9
Minimum Power Output (W)	424.2	109.6
Time to peak power (s)	2.4	1.4
Fatigue Index (%)	57.3	11.8

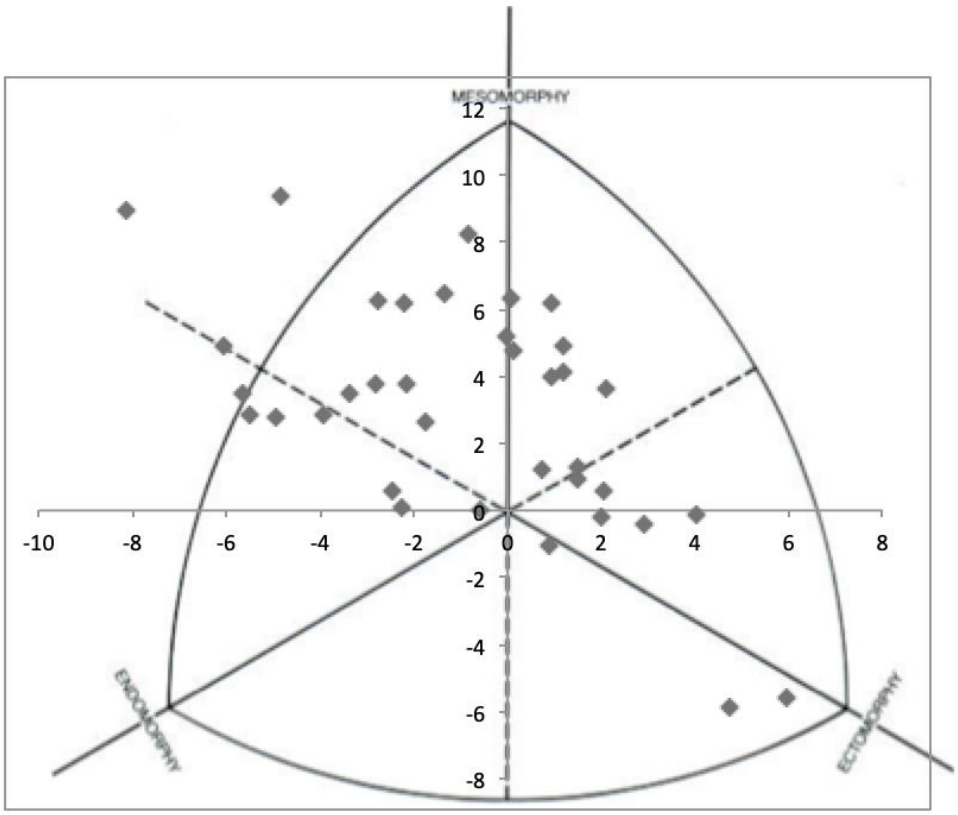


Figure 3.1: Somatotype distribution of study participants

3.4.1 Strength

Significant large positive correlations were observed between mesomorphy and 3RM chest press (r = 0.56, $p < 0.001$), mesomorphy and 3RM back squat (r = 0.55, $p < 0.001$). Non-significant medium negative correlations were observed between ectomorphy and 3RM chest press (r = -0.38, $p > 0.017$), and ectomorphy and 3RM back squat (r = -0.34, $p > 0.017$). Non-signficant small positive correlations were observed between endomorphy and 3RM chest press (r = 0.18, $p > 0.05$), and endomorphy and 3RM back squat (r = 0.08, $p > 0.05$).

Individual regression analyses indicated that mesomorphy was the best predictor of 3RM chest press performance, with 31.4% of the variance in 3RM chest press performance being accounted for by the mesomorphy rating ($p < 0.001$). A combination of mesomorphy and ectomorphy was the best predictor of 3RM back squat performance. Mesomorphy alone accounted for 30.3% of the variance in 3RM back squat performance (Step 1; $p < 0.05$), this rising to 38.8% with the addition of the ectomorphy rating into the model (Step 2; $p < 0.04$). The results from the regression analyses are shown in table 3.2. The regression models are as follows:

3 RM Chest Press (kg)= 30.42+(6.85 × mesomorphy)

3 RM back squat (kg)= -24.53+(19.80 x mesmorphy)+(10.00 x ectomorphy)

Table 3.2: Regression model for 3RM chest press (a), and 3RM back squat (b)

	B	SE B	β	Standard Error of estimates
(a)				
Constant	30.42	8.15		15.18
Mesomorphy	6.85	1.74	0.56*	
(b)				
Step 1				
Constant	43.94	12.49		23.26
Mesomorphy	10.23	2.66	0.55*	
Step 2				
Constant	-24.53	34.19		22.13
Mesomorphy	19.80	5.15	1.07*	
Ectomorphy	10.00	4.68	0.59**	

Note: R2 = 0.31 for (a). R2 = 0.30 for (b) step 1, ΔR2 = 0.09 for (b) step 2 (p < 0.05).
**p ≤ 0.001.*
*** p ≤ 0.05*

3.4.2 Anaerobic

There was a non-significant medium correlation between mesomorphy and minimum power output (r = 0.36, p = 0.03). The remaining anaerobic variables were also not significantly correlated (p > 0.05) with any somatotype components (Table 3.3).

Table 3.3 Correlation results for anaerobic parameters

Anaerobic measure	**Endomorphy**		**Mesomorphy**		**Ectomorphy**	
	Pearson's r	P value	Pearson's r	P value	Pearson's r	P value
PPO	0.06	0.74	0.10	0.55	-0.06	0.73
APO	0.10	0.56	0.26	0.12	-0.22	0.19
MPO	0.11	0.54	0.36	0.03	-0.29	0.08
FI	-0.07	0.70	-0.28	0.10	0.27	0.12
TTP	-0.32	0.06	0.04	0.84	-0.02	0.91
LaP	0.22	0.20	0.06	0.75	-0.17	0.32
La5	-0.03	0.87	0.02	0.90	0.05	0.80

PPO = Peak power output; APO = Average power output; MPO = Minimum power output; FI = fatigue index; TTP = time to peak power output; LaP = Lactate concentration post test; La5 = Lactate concentration 5 minutes post test.

3.5 Discussion

The aim of this study was to assess the relation between components of somatotype and various measures of aenaerobic performance, using both singular and multivariate analyses. The results demonstrate that there is a relationship between somatotype components and certain aspects of anaerobic performance. Mesomorphy was positively correlated with 3RM chest press, 3RM back squat and minimum power output. Although the results were not significant based on the Bonferroni correction (p < 0.017), ectomorphy exhibited a medium negative correlatation with 3RM chest press and 3RM back squat. However, most notably when considered together a combination of mesomorphy and ectomorphy best predicted 3RM back squat strength. Endomorphy demonstrated no significant correlations with any of the measured variables.

3.5.1 Strength

Mesomorphy demonstrated a large positive significant relationship with absolute strength performance in 3 RM chest press (r = 0.56, p < 0.001), and back squat (r = 0.55, p < 0.001), according to Cohen's (1988) definitions on correlation thresholds. There were non-significant medium correlations were observed between ectomorphy and 3RM chest press (r = -0.38, p > 0.017), and ectomorphy and 3RM back squat (r = -0.34, p > 0.017). Endomorphy was not significantly correlated

with strength performance. The current study recorded a broad range of somatotype ratings as evidenced by the descriptive somatotype data and the SAM value of 2.4, which Carter *et al.* (1997) indicates demonstrates marked heterogeneity of somatotype in the population sample. The results give a clear indication of the relation between somatotype and anaerobic performance across the range of different somatotypes. This makes it the first comprehensive study to determine how somatotype predicts key aspects of anaerobic performance.

The current study demonstrates a significant relationship between somatotype and lower body power. Recognising that power is derived from strength and speed (Draper and Marshall, 2013), the results of this study appear to confirm those of Saha (2014) who showed that somatotype and body composition variables are important factors in determining leg explosive power. Saha (2014) found that mesomorphy and ectomorphy components of somatotype were positively correlated with leg explosive power. The mesomorphy relation was slightly smaller than in the current study ($r = 0.55$), with $r = 0.52$ for athletes and $r = 0.43$ for non-athletes. This indicates that the relationship between explosive leg power and somatotype is remarkably similar to that between strength and somatotype. This could have important implications for using somatotype to predict performance in power-based sports.

The current study demonstrated a non-significant negative correlation between ectomorphy and upper and lower body strength performance. These findings are similar to Lewandowska *et al.* (2011) who demonstrated negative correlations between ectomorphy and various combinations of muscle torque measurements in judoists. In contrast to the current study, which identified no relation between endomorphy and any of the measured strength components, Saha (2014) reported a significant negative correlation between the endomorphy component and leg explosive power, regardless of training experience. The differences between the results reported in the current study and by Saha (2014) indicate that ectomorphy and endomorphy could be important in predicting movements where translocation of mass is required, such as in explosive leg power movements (Marta *et al.,* 2011). This is supported by results from Busko *et al.* (2013) who observed a significant correlation between ectomorphy and maximal power during countermovement jumps, but also between mesomorphy and maximal power during countermovement jumps. The current study minimised the translocation of mass by using single-plane joint movements where endomorphy had no influence and where ectomorphy hindered performance, when considered as a single

component. Low scores in ectomorphy can be advantageous in strength movements where short levers are preferential (Carter, 1970).

Multivariate analyses indicated that mesomorphy alone was the best somatotype predictor of upper body strength, whilst both mesomorphy and ectomorphy predicted lower body strength. In similar findings, Busko *et al.* (2013) indicated that the muscle torques of the upper extremities correlated significantly with the mesomorphy component only. However, in the current study the strongest prediction model of lower body strength combined both mesomorphy and ectomorphy components. In the multivariate analysis, the addition of mesomorphy appears to override the negative relation of ectomorphy to strength, such that being more slender and more muscular combine to create better lower body strength performance. Indeed, the regression model suggests that as mesomorphy increases by 1 unit, 3 RM squat performance will increase by 19.8 kg, and, as ectomorphy increases by 1 unit, 3 RM squat performance will increase by 10.0 kg. The combination of high mesomorph and ectomorph somatotype influencing lower body strength may influence decisions in sports where lower body strength is important, with recruitment not just identifying those with a predisposition to muscle mass but also with a strong linearity, potentially changing the optimum physique seen in many power based sports. The positive influence of ectomorphy on strength when combined with mesomorphy is a novel finding, and is often overlooked in studies that consider only the individual aspects of somatotype.

3.5.2 Anaerobic capacity

The current study demonstrated a non-significant medium correlation between minimum power output and mesomorphy. This indicates that a higher mesomorphy value will result in a higher minimum power value, regardless of maximal power output and may be important for events that require maintenance of power output, such as speed endurance running and cycling events (e.g. 200 m sprint in athletics or Keirin in track cycling). The current study found no significant relation between any other anaerobic components of sprint cycle performance and individual somatotype ratings. Busko *et al.* (2013) found that power output at varying external loads on a cycle ergometer correlated significantly with all components of somatotype. However, Busko *et al.*'s (2013) study only involved female volleyball athletes, all of whom were centred around the endomorphy and ectomorphy somatotypes, there being very few mesomorphic participants. This would have resulted in a skew of the data such that correlations would not have represented the full range of possible somatotype values, particularly those high in mesomorphy. The current study indicates that the

addition of higher mesomorphic values reduces the relation between somatotype and power output during sprint cycling performance such that physique is not a predicting variable for performance.

In contrast with previous research that has demonstrated a link between ectomorphy and lactate concentrations (Schreiber, 1973; Bolunchuk *et al.,* 2000), the current study did not demonstrate any significant relation between post exercise lactate following the sprint cycle and any of the somatotype components. The analytical approach of the current study in looking at the somatotype components on a continuum may be the reason for this finding. For example, the aforementioned studies studies used between group analyses of those with dominant somatotype ratings, potentially overlooking the influence that the other ratings have upon the dominant one and excluding anyone not categorised in a dominant group from the analysis.

3.5.3 Limitations

While the current study included participants representing a broad range of somatotype ratings, as indicated in the descriptive results and the SAM, the actual number of participants may have caused some instability in the regression model. Green (1991) suggests that the overall fit of a regression model is best tested when the sample size is 50 + 8k, where k is the number of predictors. In the current study, a regression model using all 3 somatotype ratings would require a sample size of 74 participants; however, Field (2009) indicates that this is an oversimplification of the situation and that the sample size needs to be based on the effect size. If Cohen's (1988) benchmark of 0.8 is used for a large effect size and when examining figures produced by Miles and Shevlin (2001) then a sample size of 40 participants is recommended for 3 predictor variables, very close to the current study sample size. A post-hoc power calculation and the correlation coefficient from each regression model for the current study data demonstrated power of 0.90 for chest press and 0.98 for back squat, both in excess of the 0.8 required power used in the a priori sample calculation.

Establishing the relationship between strength and physique could provide important information in the design of training programmes. It is important to recognise that muscular strength performance is also determined by other biological and behavioural variables (Marta *et al.,* 2011). In particular, influencing factors upon the remaining two thirds of strength performance in the current study may have included the individual impact of the chosen warm-up (Kokkonen *et al.*, 1998; Nelson and Kokkonen, 2001; Rubini *et al.*, 2007), where some participants chose to stretch and others did not,

prior to their strength exercises. Further, pre-performance mental state and nutritional status were not assessed in the current study and have previously been demonstrated to influence strength performance (Wilkes and Summer, 1984; Murphy *et al.*, 1988; Leveritt and Abernethy, 1999; Goldstein *et al.,* 2010; Wright and Smith, 2011). Indeed, the morphological state of somatotype itself can be considerably influenced by prior exposure to neural, behavioural and environmental events (Gottlieb, 2007). There may have been some variability in results as a consequence of unfamiliarity with the resistance exercises despite the familiarity sessions. Research has indicated that the 3RM back squat is a reliable assessment in Hurling players without prior resistance training experience (Byrne *et al.,* 2018). Although a different technique, assessment of the unilateral squat by 3RM has also been demonstrated as reliable in previously untrained males (McCurdy *et al.,* 2004), and Weakley and colleagues (2017) indicated trivial differences in the reliability of the bench press and front squat between experienced and inexperienced lifters.

The current study indicates that over a third of both upper and lower body strength performance is predicted by one or more somatotype components. If Ignjatovic *et al.*'s (2009) suggestion that those who are stronger have an advantage in resistance training is true, then it would seem that those with certain physiques will also have an advantage in resistance training since the prediction model suggests that a higher mesomorphy rating results in higher strength output. Any advantage in resistance training apportioned to higher mesomorphy ratings could also be related to relations between training-associated hormones (cortisol, ACTH) and somatotype, both at rest and post exercise (Handziska *et al.,* 2015). Authors have suggested that there is a relation between somatotype and trainability in children (Marta *et al.,* 2013) and young people (Ignjatovic *et al.,* 2009). Whilst training will, inevitably, alter some anthropometric characteristics relevant to somatotype, such as body weight and muscle mass, there are others that are determined by genetics (e.g. height and bone breadth) (Barbieri *et al.,* 2012). Due to the high genetic determinability of somatotype (up to 85% - Peeters *et al.,* 2003), this may mean that resistance training responses are specific to physique (Barbieri *et al.,* 2012).

Whilst there are potential practical applications with the current data set it would also be useful to further understand the physiological mechanisms behind the findings. The current methodological approach did not allow for investigating such mechanisms and so future research should seek to achieve this.

3.6 Conclusion

This study has demonstrated a link between somatotype components and certain parameters of anaerobic performance, with at least one third of strength performance predicted by one or more aspect of somatotype. In particular, it would seem that those who have high mesomorphy values are predisposed to better strength performance. In the lower body, this may also be combined with a higher ectomorphy value. In the current study, strength output demonstrated consistent relationships with two of the three somatotype components with sound theoretical underpinning and supporting research. It has demonstrated that when considering somatotype components together, a combination of mesomorphy and ectomorphy provide the best overall profile for strength performance; a novel finding in an untrained adult population. Overall, these findings may have important implications for predicting performance in sports that have a high strength profile and in the prescription of training programmes in physically active males. Further investigation is required to establish what factors contribute to the remaining two thirds of strength performance. This study fails to reject the hypothesis that there will be a significant relation between components of somatotype and anaerobic performance for certain measured variables, although when considering the components together these relationships may change in nature as per the ectomorphy and lower body strength relationship in this study.

Chapter 4: Study 2. Reliability of somatotype and measures of muscle architecture

4.1 Abstract

Measurement error can make an observed value different to the true value. The aim of this study was to assess the reliability of somatotype categories. Furthermore, this study assessed the reliability of muscle architecture measures. Sixty-eight untrained males (mean [SD] 24.8 [7.9] y; 79.8 [14.4] kg; 1.81 [0.07] m) had somatotype components calculated. Technical error of measurement (TEM) was used to calculate 95% confidence intervals (CI) for overall somatotype calculation (RTEM). CIs were calculated for ISAK accreditation Level 1 (L1TEM) and 2/3 (L23TEM) thresholds. A sample of 30 participants (mean somatotype: 10 endomorphs 5.6-4.8-1.5; 10 mesomorphs 3.3-5.9-1.6; 10 ectomorphs 2.1-2.7-4.5) had transverse and longitudinal images of upper arm, upper leg and lower leg muscle groups taken on two separate occasions to assess muscle thickness (MT) and pennation angle (PA), respectively. Coefficient of variation (CV), intra-class correlation coefficient (ICC) and standard error of the mean (SEM) were calculated to assess inter-tester and test-retest reliability. RTEM had the smallest TEM values. Detailed somatotype categorisation demonstrated larger potential for misclassification (39.7-72.1%) versus simple categorisation (29.4-38.2%). Reliability of MT was good-excellent (inter-tester CV 2.5-12.4 %; ICC 0.74-0.98; SEM 0.07-0.29 cm; test-retest CV 2.4-11.3 %; ICC 0.74-0.98; SEM 0.06-0.25 cm). Reliability of PA was poor-moderate (inter-tester CV 31.7-108.2 %; ICC 0.32-0.78; SEM 0.99-2.98 °; test-retest CV 34.5-135.0 %; ICC 0.32-0.75; SEM 0.77-3.07 °). Somatotype rating and MT via ultrasound are reliable techniques when technical skill is high. PA requires skills development and is not considered reliable in the current research.

4.2 Introduction

The study in Chapter 3 of this thesis demonstrated an assoication between somatotype components and parameters of anaerobic performance. In particular, mesomorphy rating was highly related to chest press and back squat strength, with the latter also being influenced by ectomorphy rating. Further research is required to understand some of the physiological mechanisms that contribute to the somatotype-strength relationship. In order to assess the between somatotype group differences in physiological measures, research needs to be confident that assigning participants to a dominant somatotype group is reliable. Strength output can also be determined by the architectural structure of muscle (Fukunaga *et al.,* 2001; Lieber, 2010) and so should be investigated in the current context. For this reason, reliability of muscle architecture measures should also be established to confidently determine any between group differences in these measures.

Variation in biological or mechanical (equipment) factors can result in measurement error in experimental environments (Atkinson and Nevill, 1998; Hopkins, 2000). The true value of any measure will be one that is free of measurement error (Hopkins, 2000). In reality, continuous measurements will always include some magnitude of error (Atkinson and Nevill, 1998), but the key is to try to minimize this error in order to identify actual differences or changes in performance. Retest reliability is the ability to reproduce a measure over time (Marks *et al.,* 1989; Atkinson and Nevill, 1998; Hopkins, 2000;) and can be achieved by utilising standardised and well-managed data collection (Harris and Smith, 2009). Despite this, there will always be an element of random fluctuation between measurement occasions that is largely beyond the control of the observer (Habicht *et al.*, 1979), and this error requires acknowledgement in any study. In the current thesis it is acknowledged that to confidently measure differences and change, reliability will need to be established. This chapter is primarily concerned with the reliability of somatotype categorisation, and measures of muscle architecture, muscle thickness and pennation angle via B-Mode ultrasound.

4.2.1 Anthropometric measurement error

Anthropometry is susceptible to measurement error due to variations in technique, equipment issues and human error (Harris and Smith, 2009). It is important to try to minimise this error to try to ensure measurements are as reliable and accurate as possible. ISAK have provided standardised techniques for the measurement of anthropometric variables (Stewart *et al.*, 2011). The provision of standardised protocols with exactly defined landmarks to determine a measurement, and the associated training provided by ISAK can help to decrease the imprecision and inconsistency that

accompanies measurement by individuals with poor technique (Ulijaszek and Kerr, 1999; Hume and Marfell-Jones, 2008). Reliability is often assessed using the intra-tester technical error of measurement (TEM) (Mueller and Martorell, 1988; Perini *et al.,* 2005), which determines the magnitude of the difference between repeated measures on the same participant by the same measurer. Calculation of the TEM for any anthropometric dimension will allow further computation of confidence intervals around the actual value (Perini *et al.,* 2005). This will help assess how accurately the sample mean reflects the mean in the population, giving boundaries around which the true value should fall (Field, 2009).

Somatotype (see Chapter 2) is a numerical representation of physique, quantifying the morphology and characteristics of the human body (Wilgoose and Rogers, 1949). Somatotypes are commonly reported in terms of their dominant components, with 13 categories providing in depth grouping (see table 2.3 in Chapter 2 [ROL]; Carter and Heath, 1990). However, it is also possible to simplify these 13 categories into four larger groups, each representing the dominance of endomorphy (relative adiposity), mesomorphy (musculo-skeletal robustness), or ectomorphy (linearity), or central (no dominance) (Carter, 2002; see Figure 2.3 for a summary of the three main groups). Despite the need for reliability in anthropometric measures, authors rarely report measurement errors in human populations (Arroyo *et al.,* 2010) particularly in somatotype research (Busko *et al.,* 2013, Ferrari *et al.,* 2013; Marta *et al.,* 2013; Kandel *et al.,* 2014; Grgantov *et al.,* 2017). Measurement error needs serious consideration if statistical methods are to remain uncompromised and grouping of individuals is to remain correct (Goto and Mascie-Taylor, 2007). A section of this chapter aims to demonstrate the influence of intra-tester technical error of measurement (TEM) on somatotype categorisation.

4.2.2 Reliability statistics

Reliability in performance measures common in sport science should be established with relevance to the particular investigation. As such, the day-to-day variability in measurement should be assessed to indicate the reliability of that measure (Baumgarter, 1989). When trials are repeated in controlled conditions, a measure will be considered reliable if there are small changes in the mean, low standard error of the measurement (SEM) and a high test-retest intra class correlation coefficient (ICC) (Hopkins *et al.*, 2001). The SEM is similar to the TEM used for anthropometric measurement, and is considered to be representative of absolute reliability (Eliasziw *et al.,* 1994). It follows, then, that a small SEM is indicative of a reliable measure (Atkinson and Nevill, 1998). As with

TEM, the SEM also allows for calculation of confidence intervals, which can be used to demonstrate a real change in a measured value following intervention (Baumgarter, 1989). The ICC provides an indication of the relative consistency of a measure (Weir, 2005), with values > 0.80 considered to be highly reliable (Cortina, 1993; Vincent, 1994). Another statistic that helps determine a true response is the smallest detectable difference (SDD) (Beckerman *et al.,* 2001). This is representative of the minimum change representing a real difference beyond zero (Bernards *et al.*, 2017), and can be used in intervention studies to establish the reality of any difference between measurement points. The coefficient of variation (CV) is a commonly expressed reliability measure in sport and exercise research (Atkinson and Nevill, 1998), and there previously appeared to be an arbitrary goal of the CV being 10% or lower (Stokes, 1985). However, more recently researchers have begun to set criterion for acceptable CV% in direct relation to their usefulness to establish within-subject variability (Byrne *et al.,* 2017). The setting of a CV criterion for muscle architecture measures will be discussed in section 4.2.3. Another common method of reliability assessment is Bland-Altman plots and associated limits of agreement (LOAs) (Bland and Altman, 1986), which can be expressed as a range covering total error (a combination of bias and random error) (Atkinson and Nevill, 1998). However, Hopkins (2000) favours typical error (SEM then used to calculate SDD or similar) over LOAs because of the latter's reliance on larger sample sizes.

4.2.3 Muscle architecture measurement error

Architectural structure of muscle can determine function and therefore strength output (Fukunaga *et al.,* 2001; Lieber, 2010). Ultrasound has been demonstrated to be valid and reliable for the assessment of human muscle architecture (Howe and Oldham, 1996; Narici *et al.,* 2004; Noorkoiv *et al.,* 2010; Thomaes *et al.,* 2012), with any value of ICC 0.75-0.90 considered good, and anything above 0.90 considered excellent (Koo and Li, 2016). In particular, muscle thickness (MT) has evidence of varied intra-tester and test-retest ICCs for different muscles in a range of different populations (see table 4.1), although the majority of these appear to fall above the 0.75 threshold set by Koo and Li (2016) for good reliability.

Table 4.1: Summary of ICC research when measuring MT with ultrasound

Study	Participants	Muscles Measured	ICC (unless otherwise stated)
Weiss and Clarke (1985)	Healthy young (18-28 y) males and females	Gastrocnemius	Males T-R 0.98 Females T-R 0.99
	7-9 year old children	Biceps brachii	T-R Boys 0.99, girls 0.98

Weiss (1987)		Triceps brachii	T-R Boys 0.91, girls 0.94
Abe *et al.* (1994)	Japanese adults	Biceps brachii, triceps brachii, quadriceps, hamstrings, gastrocnemius	T-R r = 0.96-0.99
Reimers *et al.* (1996)	350 adult patients with neuromuscular diseases	Rectus femoris Vastus intermedius Gastrocnemius Soleus	T-R 0.98 for all
Reeves *et al.* (2004)	Six healthy adults	Vastus lateralis	T-R 0.99
Alegre *et al.* (2006)	36 physically active male students	Vastus lateralis	T-R 0.99
Blazevich *et al.* (2006)	Untrained male (n = 15) and female (n = 16) adults.	Vastus lateralis Vastus medialis Vastus intermedius Rectus femoris	T-R r = 0.88-0.97
Mohagheghi *et al.* (2007)	Children with spastic hemiplegic cerebral palsy (7 males, 1 female)	Gastrocnemius	Paretic leg T-R 0.94 Non-paretic leg T-R 0.93
Thoirs and English (2009)	Healthy adults in standing position	Anterior upper arm Posterior upper arm Anterior thigh Posterior thigh Posterior lower leg	T-R 0.89, T-R 0.91, T-R 0.89, T-R 0.70, T-R 0.83
Moreau *et al.* (2009)	Adolescents with spastic cerebral palsy (CP; n = 18) and age-matched typically developing (TD; n = 12)	Rectus femoris Vastus Lateralis	TD IT 0.98 CP IT 0.99 TD IT 0.99 CP IT 0.99
Legerlotz *et al.* (2010)	Healthy boys (n = 13) and girls (n = 8) aged 4-10 years.	Gastrocnemius	IT 0.96
Pinto *et al.* (2012)	Un-resistance-trained young males	Biceps brachii	T-R 0.96
Strasser *et al.* (2013)	26 young (<35 years) healthy adults	Rectus femoris Vastus intermedius Vastus lateralis Vastus medialis	T-R 0.97 T-R 0.98 T-R 0.96 T-R 0.98
Santos and Silva (2016)	20 healthy untrained adults (10 male, 10 female)	Vastus medialis Vastus lateralis Rectus femoris Vastus medialis	IT 0.98; T-R 0.98 IT 0.98; T-R 0.81 IT 0.99; T-R 0.92 IT 0.97; T-R 0.89 IT 0.88

Vieira *et al.* (2016)	50 young healthy females	Bicep brachii and brachialis combined	
Freitas *et al.* (2017)	20 healthy adults (10 male, 10 females)	Biceps femoris	IT 0.95; BT 0.88; T-R 0.86

T-R = test-retest reliability, IT = intra-tester (within session) reliability; BT = inter-tester reliability

CVs have been established for MT for inter (1.5-6.0%) and intra-tester (2.3-5.0%) reliability at various muscle sites (Campbell *et al.,* 1995; Reimers *et al.*, 1998; Legerlotz *et al.*, 2010; Vieira *et al.,* 2016), and for test-retest (2.1-7.4%) (Reimers *et al.,* 1993; Reimers *et al.,* 1996; Alegre *et al.,* 2006; Legerlotz *et al.*, 2010). This range of values were considered acceptable levels of reliability against the criteria set by the previous research studies and allows for a criterion to be set within this range of coefficients. For MT SEM reliability is established if the SEM falls below 10% of the mean value (Santos and Armada-da-Silva, 2016; Vieira *et al.,* 2016; Freitas *et al.,* 2017). The SEM is more commonly used to calculate the SDD. Although threshold values are rarely established for the SDD because of its specificity to the population sample, values ranging from 6.6 to 21.9% of the mean value have been demonstrated in various muscles (Santos and Armada-da-Silva, 2016; Vieira *et al.,* 2016; Freitas *et al.,* 2017). Good test-retest reliability in the current research study's population would allow ultrasonic measurement of muscle thickness to confidently identify if differences in the hypertrophic response to exercise exist between somatotype groups.

A further measure often sampled with ultrasound is pennation angle (PA). This is the angle at which the fibres are arranged compared to the long axis of the muscle and is measured by assessing the angle of the fibres compared to the deep fascia of the muscle (Strasser *et al.,* 2013). PA is related to strength output since a larger PA allows for more contractile units, giving the muscle greater potential to produce force (Kawakami *et al.,* 1993). Reliability results for PA are variable (see Table 4.2). Intra-tester and test-retest CV have been demonstrated as acceptable at 0-6.0% (Kawakami *et al.*, 1998; Legerlotz *et al.*, 2010) and 4.0-6.0% (Alegre *et al.,* 2006; Legerlotz *et al.*, 2010) respectively. There is little publication of SEM and SDD data for PA. Freitas and colleagues (2017) presented SEMs below 10% for PA of biceps femoris in healthy young adults and indicated that an SDD of 11.4% would be required to establish a real change following intervention. It has been suggested that reliability for PA may be affected by operator differences as the angle of the probe will change the measured PA (Benard *et al.,* 2009; Strasser *et al.,* 2013). It is important, therefore to establish reliability on a study-by-study basis.

Table 4.2: Summary of ICC statistics from previous research measuring PA with ultrasound

Study	Participants	Muscles Measured	ICC
Chleboun *et al.* (2001)	18 healthy female adults	Biceps femoris	IT 0.87
Mairet *et al.* (2006)	19 healthy adults (10 male, 9 female)	Vastus lateralis	IT 0.99
Mohagheghi *et al.* (2007)	Children with spastic hemiplegic cerebral palsy (7 males, 1 female)	Gastrocnemius	Paretic leg T-R 0.0.85 Non-paretic leg T-R 0.88
Moreau *et al.* (2009)	Adolescents with spastic cerebral palsy (CP; n = 18) and age-matched typically developing (TD; n = 12)	Rectus femoris Vastus Lateralis	TD IT 0.95 CP IT 0.97 TD IT 0.96 CP IT 0.97
Legerlotz *et al.* (2010)	Healthy boys (n = 13) and girls (n = 8) aged 4-10 years.	Gastrocnemius	IT 0.91
Strasser *et al.* (2013)	26 young (<35 y) healthy adults	Vastus intermedius Vastus lateralis Vastus medialis	T-R 0.78 T-R 0.53 T-R 0.44
Freitas *et al.* (2017)	20 healthy young adults (10 male, 10 female)	Biceps femoris	IT 0.80; BT 0.51; T-R 0.70

T-R = test-retest reliability, IT = intra-tester (within session) reliability; BT = inter-tester reliability

This chapter will look to examine reliability specific to somatotype in the form of TEMs and 95% confidence intervals for somatotype rating. It was hypothesised that 95% confidence intervals will be small when measurements were taken by the researcher, and that these intervals will increase if calculated using ISAK accreditation standards. It is expected that TEM must remain low for confidence in somatotype grouping to be established. It was also hypothesised that simple categorisation (i.e. mesomorph, ectomorph, endomorph, central) would result in fewer miscategorisations than more complex grouping (e.g. endo-mesomorph, ectomorph-mesomorph). Reliability was also assessed for muscle ultrasound measures in order to establish their feasibility for use in further studies in non-resistance trained participants from a variety of somatotype groups. From the previous research reviewed, it was hypothesised that good reliability would be established for measures of muscle thickness and pennation angle.

4.3 Methods

The methodology presents the research participants, design, procedures and analysis of two stages to the reliability study: i) somatotype, ii) muscle architecture.

4.3.1 Somatotype

4.3.1.1 Participants

Sixty-eight untrained but physically active males (mean [SD] 24.8 [7.9] y; 79.8 [14.4] kg; 1.81 [0.07] m) were recruited to the study from the local community including university and hospital (staff) settings. All participants were provided with an information sheet and consent form, detailing the purpose of the study and their right to withdraw at any time without any disadvantage of any kind, prior to the start of testing. As such participants provided written informed consent to participate in the study (Appendix 2b and c). The study received approval from the Faculty Ethics Committee (see Appendix 2a).

4.3.1.2 Design

Participants were recruited initially using purposive sampling for the initial body composition assessment, with the requirement that they be untrained (no planned and structured exercise programme undertaken in the last 6 months but could still be physically active). Participants were tested on one occasion and were instructed to attend the session fully hydrated and having refrained from intense physical activity for the 24 hours preceding testing. The research study adopted a quantitative approach using primary data collection. Anthropometric measures were taken from the participant, with a minimum of two measures taken at each site. If a difference existed between the first two measures of < 5 % for skinfolds and < 1 % for all other measures, a third measure was taken. The two closest values were transferred to the TEM calculation.

4.3.1.3 Procedures

Participants' anthropometric profiles were measured by a Level 3 ISAK anthropometrist using ISAK protocols (Stewart *et al.,* 2011), and somatotype calculated in line with the methods outlined for somatotype in Chapter 3 (section 3.3.4 Somatotype assessment). Mean technical error of measurement for skinfolds was 2.2% and for all other measures was 0.2%. Overall mean (± standard deviation) somatotype was: endomorphy 3.5 (± 1.8), mesomorphy 4.4 (± 1.6), ectomorphy 2.6 (± 1.6).

4.3.1.4 Statistical analysis

Technical error of measurement was calculated for each individual anthropometric variable using the following equation:

$$TEM = \sqrt{\frac{\Sigma (sd)^2}{2n}}$$

where sd = standard deviation (of two repeat measurements) and n = number of participants measured.

This was then used to calculate 95% confidence intervals for the individual variables, and for the overall somatotype calculation. Further, TEMs equivalent to those who train to become ISAK Level 1 (7.5% for skinfolds, 1.5% for all other measures) and Level 2/3 (5.0% for skinfolds, 1.0% for all other measures) in the post-course guidelines (Stewart *et al.,* 2011) were calculated and used to calculate equivalent 95% confidence intervals for theoretical operaters at the relevant qualification thresholds. Each individual participant was assigned a detailed and a simplified somatotype category (see Chapter 2 for more information on these categories). It was further analysed if they were still assigned to this category based on their 95% confidence intervals from the researcher's TEM (RTEM), a theoretical Level 1 ISAK anthropometrist TEM (L1TEM) or a theoretical Level 2/3 ISAK anthropometrist TEM (L23TEM) based on the allowable accreditation thresholds for these levels.

4.3.2 Muscle architecture

4.3.2.1 Participants

A sample of 30 male participants from the 68 used for somatotype reliability (10 endomorphs mean [SD] 25 [6] y; 1.82 [0.06] m; 93.5 [18.9] kg; mean somatotype 5.6-4.8-1.5; 10 mesomorphs 24 [4] y; 1.76 [0.06] m; 80.3 [9.2] kg; mean somatotype 3.3-5.9-1.6 10 ectomorphs 21 [2] years; 1.84 [0.07] m; 68.7 [7.0] kg; mean somatotype 2.1-2.7-4.5) were recruited to the study. All participants were provided with an information sheet and consent form (Appendix 2b and c), detailing the purpose of the study and their right to withdraw at any time without any disadvantage of any kind, prior to the start of testing. As such participants provided written informed consent to participate in the study. The study received approval from the Faculty Ethics Committee (see Appendix 2a).

4.3.2.2 Research Design

The research study adopted a quantitative group comparisons approach using primary data collection. Participants were recruited initially using purposive sampling for the initial body composition assessment, with the requirement that they be untrained (no planned and structured

exercise programme undertaken in the last 6 months but could still be physically active). Following anthropometric data collection and calculation of somatotype, participants were assigned to a group on the basis of being dominant (one half unit higher) in that somatotype. If they were not considered dominant then they were excluded from the study. Participants were tested on two separate mornings with at least one week between sessions. Participants were requested to attend testing fully hydrated, having eaten 1-2 hours prior to testing and having abstained from alcohol, caffeine or cigarette smoking within 12 hours of testing, and strenuous exercise within 24 hours of testing. Muscle architecture measures were taken in triplicate at each site for each participant by two investigators with basic training in analysis of ultrasound images on each of the two visits.

4.3.2.3 Procedures

Participants' anthropometric profiles were measured by a Level 3 ISAK anthropometrist using ISAK protocols (Stewart *et al.,* 2011) and somatotype calculated in line with the methods outlined for somatotype in Chapter 3 (Section 3.3.4 Somatotype Assessment). Mean technical error of measurement for skinfolds was 2.5% and for all other measures was 0.3%.

Participants underwent ultrasound assessment of upper (biceps and triceps) and lower (hamstrings, quadriceps, calves) body muscle groups (see Figure 4.1) using B-Wave ultrasound (u smart 3300, Terason, USA) with a multi-frequency linear transducer (15-4 MHz wave frequency). Images were taken in both the transverse (thickness) and longitudinal (pennation angle) plane with the participants standing with weight evenly distributed on both legs. Ultrasound images were taken at the marked locations for triceps and biceps skinfold site, front thigh skinfold site and a marked tracked posteriorly from this onto the mid-hamstring, and at a mark tracked posteriorly from the medial calf skinfold site.

Images were analysed for muscle thickness and pennation angle using the in-built callipers (see Figure 4.2). Muscle thickness was assessed as the distance from the adipose-tissue–muscle interface and muscle–bone interface at the middle of the image (Abe *et al.,* 1994). Pennation angle is the measured angle between the fibres and the deep fascia of the muscle (Strasser *et al.,* 2013).

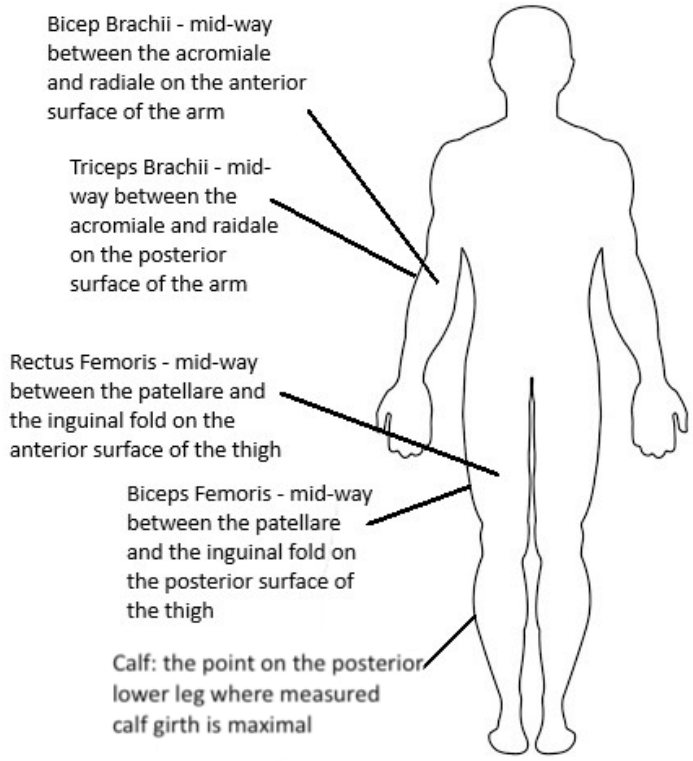
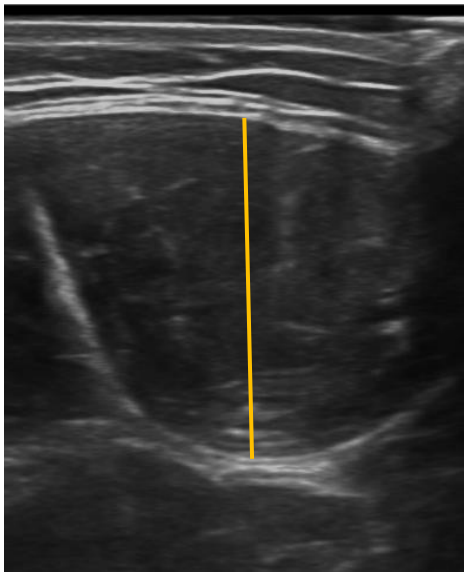


Figure 4.1: Location of ultrasound probe placement

(Using skinfold locations in Stewart et al., 2011)
N.B. Calf location describes placement for both gastrocnemius and soleus measurements.

a.) 

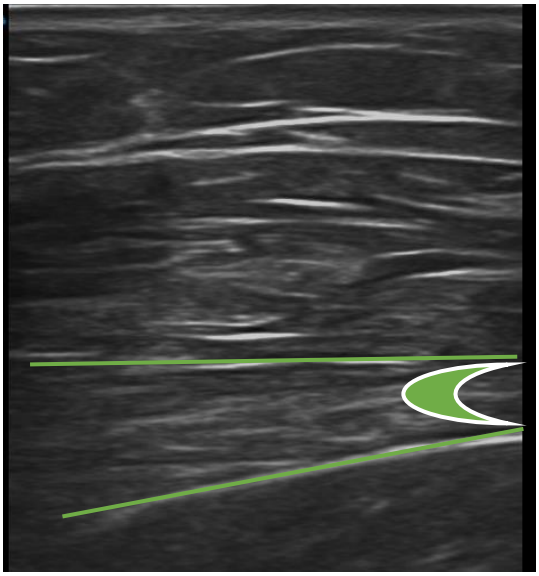
b.) 

Figure 4.2: Image provided by B-Mode ultrasound for a.) muscle thickness and b.) pennation angle

Yellow line on a.) indicates muscle thickness measurement location. Green semi-circle on b.) indicates pennation angle measurement.

4.3.2.4 Statistical analysis

Inter-tester reliability for muscle thickness and pennation angle was measured by having two investigators separately analyse the images taken. Test-restest reliability was established by comparing results from session one to session two for the primary investigator's analysis. CV was calculated as follows:

$$\frac{SD}{\mu}$$

where SD is the standard deviation and μ is the mean of the measured variable. Based on the range of values outlined in the introduction of this chapter, a measure was considered reliable if the CV fell below 7.5% (the highest value for a CV in MT or PA in the literature being 7.4%).

The ICC was calculated according to the formula:

$$\frac{SD_b^2}{(SD_b^2+SD_w^2)}$$

where SD_b^2 and SD_w^2 are the between and within-subject variance of the measured variable, respectively. Based on the guideance from Koo and Li (2016), if a MT or PA measure had an ICC 0.75-0.90 it had good reliability, anything above 0.90 was considered excellent.

SEM was calculated:

$$SEM = SD* \sqrt{(1-ICC)}$$

In line with previous literature outlined in the introduction, the reliability criterion for SEM was set at < 10% of the mean value.

The smallest detectable difference (SDD) is the minimum amount of change in a score that ensures the change isn't the result of measurement error and was calculated as follows:

$$SDD = 1.96 \times SEM \times \sqrt{2},$$

where 1.96 corresponds to 95% confidence interval and the square root of 2 is to adjust for sampling from two different measurements—represents the 95% confidence that a change in the measurement exceeding this threshold is true and reliable and not just a measurement error. The SDD is presented in units of the specific measurement. It is not used to determine reliability per se, but as an indicator for the magnitude of measurement required in future intervention studies to determine a real change.

The first criterion for acceptable relative reliability was for the ICC measure to be ≥0.75 in line with previously used guideline for muscle architecture analysis (Koo and Li, 2016). The second criterion for acceptable absolute reliability was for the CV % below 7.5. The third criterion required the SEM to be < 10% of the mean value. The measures estimated acceptable reliability when all three criteria were met.

4.4 Results

4.4.1 Somatotype

Mean (± SD) somatotype component values were Endomorphy 3.5 (± 1.8), Mesomorphy 4.4 (± 1.6), Ectomorphy 2.6 (± 1.6) across the sample population. SADs ranged from 0.1 to 6.8, and the SAM was 2.5 somatotype units. Calculation of somatotypes demonstrated a range of values with extremes in each of the three classifications (Figure 4.3). RTEM provided the smallest average TEM (0.05 somatotype units) and range of 95% confidence intervals (Figure 4.4), with the average TEM (0.11 somatotype units) and this range increasing with L23TEM (Figure 4.5) and increasing even further with L1TEM (TEM 0.16 somatotype units) (Figure 4.6).

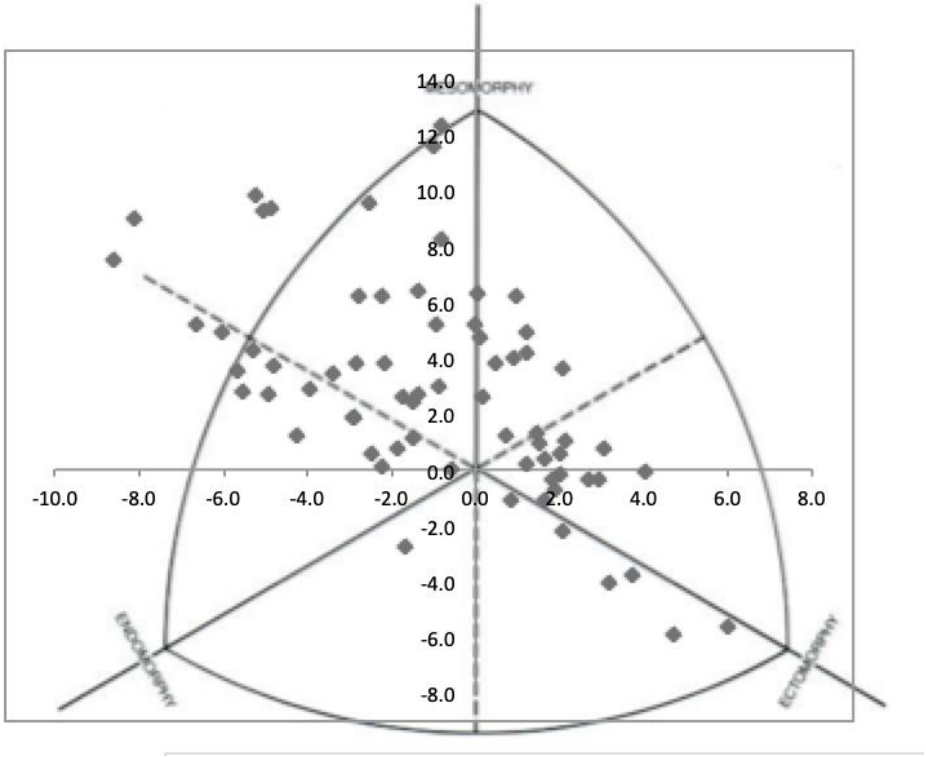


Figure 4.3: Somatotype distribution of study participants

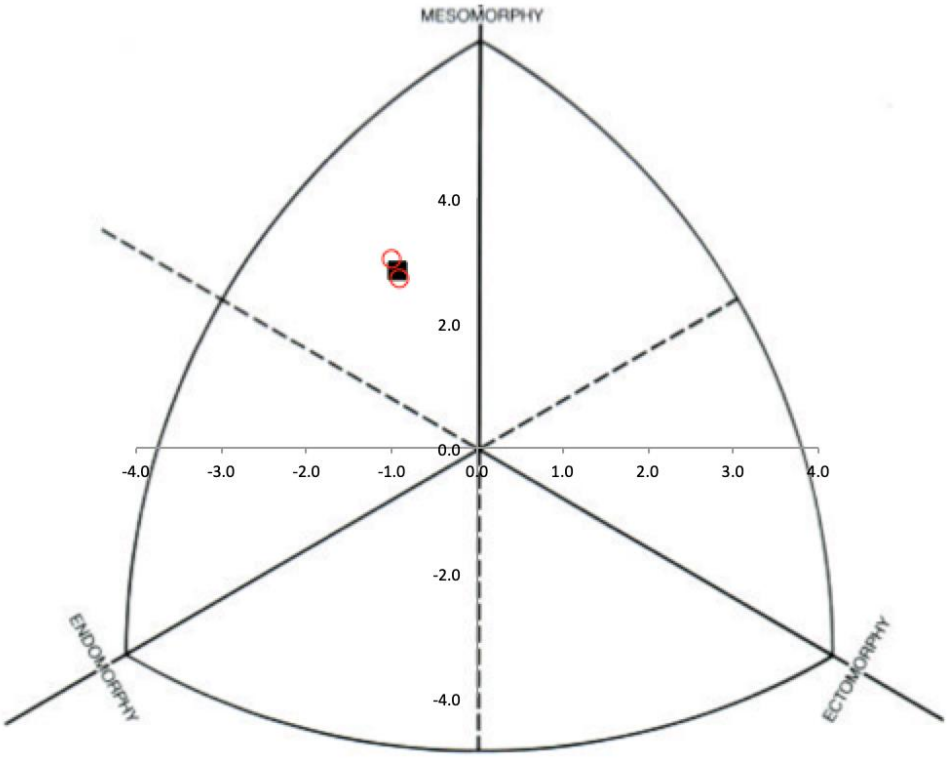


Figure 4.4: Mean somatotype for population with RTEM mean ranges.

■ = population mean. O = RTEM 95% confidence intervals.

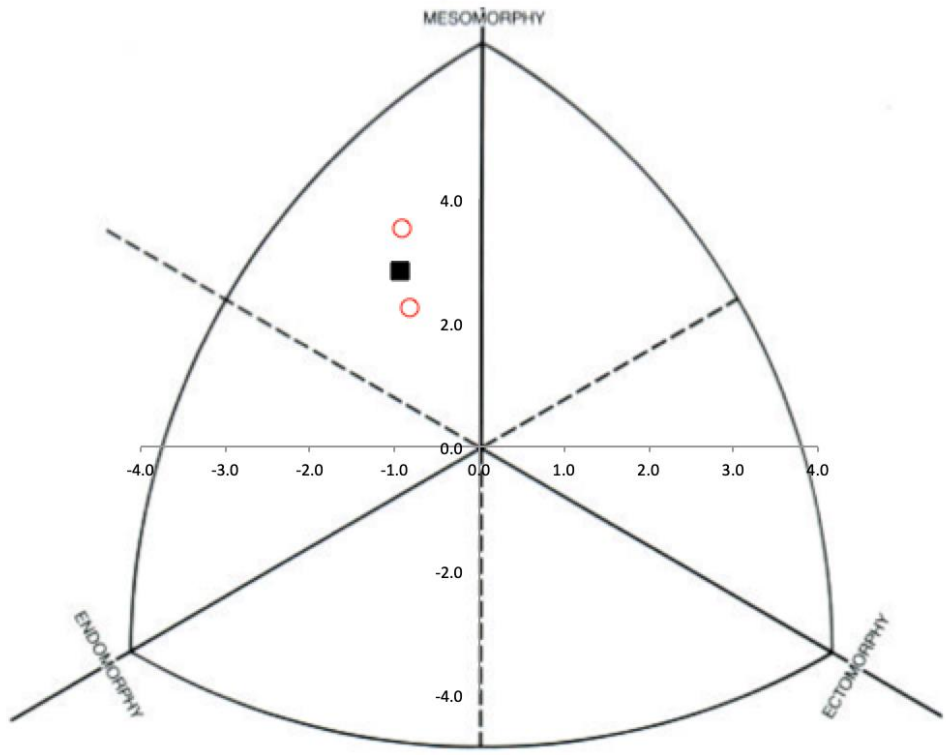


Figure 4.5: Mean somatotype for population with L23TEM mean ranges.

■ *= population mean.* **O** *= RTEM 95% confidence intervals.*

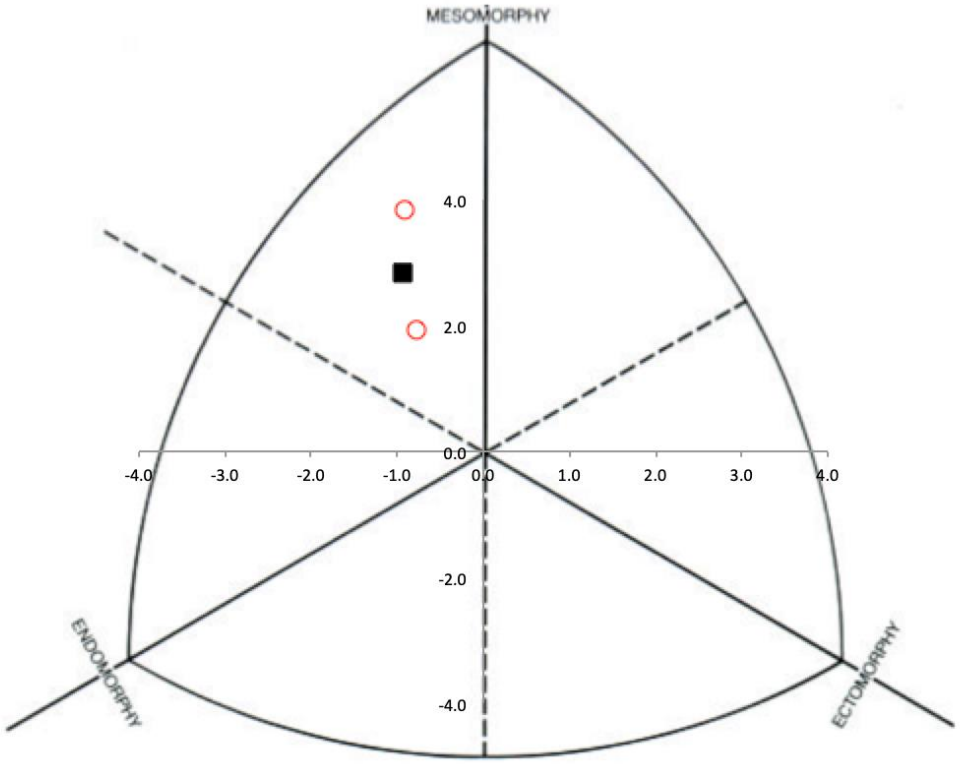


Figure 4.6: Mean somatotype for population with L1TEM mean ranges.

■ *= population mean.* **O** *= RTEM 95% confidence intervals.*

The influence of 95% confidence intervals on categorisation of somatotype is shown in Table 4.3. Simplified categorisation of somatotype was more accurate for all intra-tester reliability levels, with the RTEM potentially misclassifying 29.4%, L23TEM 35.3% and L1TEM 38.2% respectively. With the RTEM only four participants could have been misclassified into a completely different somatotype category (1 x central, 1 x non-dominant mesomorph, 1 x non-dominant endomorph and 1 x non-dominant ectomorph). All other participants still had their highest number in the dominant category, even if they went from dominant (more than 0.5 units higher) to non-dominant or vice versa. This increased to 5 participants for L23TEM and 15 participants for L1TEM, with the majority of these being those in non-dominant categories. The potential to misclassify somatotype was higher for detailed somatotype category with RTEM potentially misclassifying 39.7%, L23TEM 61.8%, and L1TEM 72.1% respectively.

Table 4.3: Percentage of participants potentially mis-classified based on 95% confidence intervals

Somatotype category	RTEM	L23TEM	L1TEM
Detailed	39.7%	61.8%	72.1%
Simplified	29.4%	35.3%	38.2%

4.4.2 Ultrasound Muscle Architecture

The criterion value of <7.5% for CV was met for all measures for inter-tester reliability apart from triceps MT (10.79%), hamstring MT (8.85%) and calf (soleus) (12.38%) in the mesomorph population. ICC values generally exceeded the 0.75 ICC threshold for good reliability (Table 4.4). Hamstring (0.69) and calf (soleus) (0.74) ICC values in the mesomorph population were below the threshold. SEM values ranged from 2.3% to 10.3% of the mean, with the soleus in the mesomorph group being the only value to exceed the 10% criterion. SDD values were lowest for Gastrocnemius (0.22 cm), bicep brachii (0.26 cm), and rectus femoris (0.27 cm).

Inter-tester reliability statistics for PA are shown in Table 4.5. Inter-tester reliability measures for PA exceeded the criterion thresholds for all muscles in each somatotype group.

Table 4.4: Reliability of inter-tester MT measures

Muscle	Somatotype	Mean (cm)	CV (%)	ICC	SEM (cm)	SDD (cm)
Bicep brachii	Endomorph	2.96	2.48	0.98	0.07	0.20
	Mesomorph	3.58	3.62	0.97	0.13	0.36
	Ectomorph	2.87	2.82	0.96	0.08	0.22
	Overall	*3.14*	*2.97*	*0.97*	*0.09*	*0.26*
Triceps brachii	Endomorph	2.82	3.73	0.97	0.10	0.28
	Mesomorph	3.11	10.79	0.77	0.28	0.78
	Ectomorph	2.83	5.43	0.93	0.14	0.39
	Overall	*2.92*	*6.65*	*0.89*	*0.17*	*0.48*
Hamstring (biceps femoris)	Endomorph	3.55	4.34	0.94	0.14	0.39
	Mesomorph	3.79	8.85	0.69	0.29	0.79
	Ectomorph	3.35	2.61	0.98	0.08	0.24
	Overall	*3.56*	*5.27*	*0.87*	*0.17*	*0.47*
Quad (rectus femoris)	Endomorph	2.65	3.63	0.98	0.09	0.25
	Mesomorph	2.95	4.85	0.94	0.14	0.38
	Ectomorph	2.46	2.47	0.98	0.06	0.17
	Overall	*2.69*	*3.65*	*0.96*	*0.10*	*0.27*
Gastrocnemius	Endomorph	2.13	4.83	0.89	0.10	0.27
	Mesomorph	1.95	4.06	0.91	0.08	0.21
	Ectomorph	1.86	3.84	0.97	0.07	0.18
	Overall	*1.98*	*4.24*	*0.92*	*0.08*	*0.22*
Soleus	Endomorph	1.74	7.03	0.87	0.11	0.31
	Mesomorph	1.84	12.38	0.74	0.19	0.52
	Ectomorph	1.68	6.24	0.90	0.10	0.28
	Overall	*1.75*	*8.55*	*0.83*	*0.13*	*0.37*

Table 4.5: Reliability of inter-tester PA measures

Muscle	Somatotype	Mean (°)	CV (%)	ICC	SEM (°)	SDD (°)
Bicep brachii	Endomorph	2.71	74.91	0.32	1.06	2.94
	Mesomorph	2.75	64.61	0.52	1.08	2.99
	Ectomorph	2.22	71.81	0.53	0.99	2.73
	Overall	*2.56*	*70.44*	*0.46*	*1.04*	*2.89*
Triceps brachii	Endomorph	6.04	53.08	0.61	2.14	5.94
	Mesomorph	8.06	52.71	0.54	2.87	7.94
	Ectomorph	6.91	56.76	0.59	2.58	7.13
	Overall	*7.00*	*54.18*	*0.58*	*2.53*	*7.00*
Hamstring (biceps femoris)	Endomorph	4.97	51.11	0.70	1.80	4.98
	Mesomorph	6.85	108.17	0.45	2.72	7.53
	Ectomorph	3.84	67.63	0.70	1.80	4.98
	Overall	*5.22*	*75.63*	*0.62*	*2.10*	*5.83*
Quad (rectus femoris)	Endomorph	5.66	63.37	0.40	2.02	5.58
	Mesomorph	5.66	71.85	0.49	2.18	6.05
	Ectomorph	5.06	72.47	0.51	1.94	5.37
	Overall	*5.46*	*69.23*	*0.46*	*2.05*	*5.67*
Gastrocnemius	Endomorph	7.01	45.41	0.51	2.10	5.83
	Mesomorph	8.33	31.65	0.78	1.84	5.10
	Ectomorph	7.75	40.55	0.61	1.94	5.39
	Overall	*7.70*	*39.20*	*0.69*	*1.88*	*5.44*
Soleus	Endomorph	10.59	41.74	0.65	2.98	8.26
	Mesomorph	9.33	75.46	0.61	2.87	7.96
	Ectomorph	10.18	42.78	0.63	2.91	8.05
	Overall	*10.03*	*53.33*	*0.62*	*2.97*	*8.09*

The criterion value of <7.5% for CV was met for all measures for test-retest reliability with the exceptions of triceps MT (9.45%) and calf (soleus) (11.33%) in the mesomorph population (Table 4.6). ICC values generally exceeded the 0.75 ICC threshold for good reliability. Only Hamstring (0.74) ICC in the mesomorph population was below this threshold. SEM values ranged from 2.5% to 10.0% of the mean, with the SEM of the soleus in the mesomorph group being exactly 10% of the measured mean. SDD values were lowest for Gastrocnemius (0.23 cm), bicep brachii (0.29 cm), and rectus femoris (0.29 cm).

Table 4.6: Test-retest reliability of MT measures

Muscle	Somatotype	Mean (cm)	CV %	ICC	SEM (cm)	SDD (cm)
Bicep brachii	Endomorph	3.03	3.25	0.96	0.09	0.26
	Mesomorph	3.49	4.55	0.92	0.16	0.44
	Ectomorph	2.85	2.38	0.98	0.07	0.18
	Overall	*3.12*	*3.39*	*0.95*	*0.11*	*0.29*
Triceps brachii	Endomorph	2.97	4.06	0.95	0.12	0.33
	Mesomorph	3.13	9.45	0.84	0.25	0.69
	Ectomorph	2.72	6.04	0.87	0.15	0.40
	Overall	*2.94*	*6.52*	*0.89*	*0.17*	*0.47*
Hamstring (biceps femoris)	Endomorph	3.54	5.31	0.91	0.17	0.47
	Mesomorph	3.84	7.04	0.74	0.24	0.66
	Ectomorph	3.15	3.11	0.97	0.09	0.26
	Overall	*3.51*	*5.15*	*0.87*	*0.17*	*0.46*
Quad (rectus femoris)	Endomorph	2.76	3.96	0.97	0.10	0.28
	Mesomorph	2.96	5.52	0.93	0.16	0.44
	Ectomorph	2.41	2.40	0.98	0.06	0.15
	Overall	*2.71*	*3.96*	*0.96*	*0.10*	*0.29*
Gastrocnemius	Endomorph	2.16	5.71	0.84	0.11	0.31
	Mesomorph	1.92	3.88	0.93	0.07	0.20
	Ectomorph	1.82	3.96	0.97	0.07	0.18
	Overall	*1.97*	*4.52*	*0.91*	*0.08*	*0.23*
Soleus	Endomorph	1.76	7.12	0.87	0.11	0.31
	Mesomorph	1.90	11.33	0.78	0.19	0.52
	Ectomorph	1.66	5.81	0.92	0.09	0.25
	Overall	*1.77*	*8.09*	*0.85*	*0.13*	*0.36*

Test-retest reliability statistics for PA are shown in Table 4.7. Test-retest reliability measures for PA exceeded the criterion thresholds for all muscles in each somatotype group.

Table 4.7: Test-retest reliability of PA measures

Muscle	Somatotype	Mean (°)	CV %	ICC	SEM (°)	SDD (°)
Bicep brachii	Endomorph	2.73	70.84	0.37	1.03	2.85
	Mesomorph	2.73	68.41	0.44	1.07	2.97
	Ectomorph	2.21	61.99	0.40	0.77	2.12
	Overall	*2.56*	*67.08*	*0.40*	*0.95*	*2.65*
Triceps brachii	Endomorph	6.53	44.06	0.70	2.03	5.62
	Mesomorph	8.17	52.55	0.45	2.81	7.79
	Ectomorph	5.95	53.08	0.52	2.12	5.88
	Overall	*6.88*	*49.89*	*0.55*	*2.32*	*6.43*
Hamstring (biceps femoris)	Endomorph	4.32	49.02	0.73	1.51	4.18
	Mesomorph	5.85	135.03	0.46	2.72	7.55
	Ectomorph	3.37	64.11	0.75	1.52	4.22
	Overall	*4.51*	*82.72*	*0.65*	*1.92*	*5.32*
Quad (rectus femoris)	Endomorph	5.13	67.02	0.32	1.92	5.33
	Mesomorph	5.10	85.44	0.44	2.19	6.08
	Ectomorph	5.14	70.16	0.36	1.81	5.02
	Overall	*5.12*	*74.21*	*0.37*	*1.98*	*5.48*
Gastrocnemius	Endomorph	6.81	47.91	0.49	1.97	5.46
	Mesomorph	8.19	34.46	0.69	1.97	5.45
	Ectomorph	7.73	35.30	0.63	1.75	4.85
	Overall	*7.58*	*39.22*	*0.60*	*1.90*	*5.25*
Soleus	Endomorph	13.61	34.79	0.52	3.07	8.51
	Mesomorph	11.34	36.56	0.40	2.41	6.67
	Ectomorph	12.24	35.77	0.65	2.97	8.22
	Overall	*12.40*	*35.71*	*0.52*	*2.81*	*7.80*

4.5 Discussion

The results of this study demonstrate that TEM should be taken into account when calculating somatotype category. A lower TEM reduces the chance of mis-categorising a person with respect to their somatotype, and increases the reliability of determining the dominant somatotype in a simplified categorisation. The assessment of muscle thickness measured via B-Mode ultrasound demonstrated good-excellent inter-tester and test-retest reliability, but pennation angle was poor-moderate for both measures. This indicates that in the current population muscle thickness can be used to reliably assess between-group and time-course differences, but pennation angle results would have to be interpreted with caution.

4.5.1 Somatotype

The results from the somatotype reliability study demonstrate that technical error can have an impact on somatotype calculations. Even with the high technical skill of the researcher in this study the chance of misclassification remains close to one third (29.4%). Therefore, researchers should be aiming for TEMs <2.5% for skinfolds and <0.5% for all other measures. When TEM is at ISAK Level 1 accreditation threshold, there is a larger spread of values on the somatochart compared to those of

a higher technical competency. The reliability of somatotype also demonstrates that mis-categorisation occurs more often with higher TEMs and with a detailed approach to classification. There are very few papers that report TEM as standard, and there are no other known papers that look specifically at how error can affect somatotype categorisation.

The researcher in the current study demonstrated similar TEMs to the study by Bolonchuk and colleagues (2000) who assessed the relationship between somatotype and function during exercise. The authors reported their technical error to be less than 0.2 somatotype units (compared to less than 0.1 for the researcher TEM in the current study), and grouped their participants with simple dominance, and so with a similar error to the current study would likely experience a mis-categorisation of 19 participants of 63. Despite this they demonstrated a difference in function during exercise between the somatotype groups, with ectomorphs in particular showing different values to those grouped as meso- and endomorphs. Ectomorphs appear to be the least susceptible to mis-categorisation via technical error and so observations in this group are likely to be a true representation. In a study with a similar focus, participants were grouped according to dominant somatotype in the more detailed form with 9 endo-mesomorphs, 11 mesomorphs, 12 meso-ectomorphs and 9 ectomorphs following a 12-week endurance training programme (Chaouachi *et al.,* 2005). However, despite the author taking multiple measures on each participant there is no mention of the magnitude of error within this paper. Given that the expertise of the investigator is also not referred to, it is possible that up to 72% of participants (30 of 41) were mis-categorised, leaving the results highly questionable. Given that this thesis is particularly concerned with training response based on somatotype, this demonstrates the importance of reporting reliability data when assessing any relationships.

Studies that group participants according to somatotype category should take into account measurement error and indicate any potential mis-categorisations. It is also recommended that those studies keep their categorisation system simple rather than increasing potential mis-categorisation through a detailed system.

4.5.2 Ultrasound Muscle Architecture

Inter-tester reliability for MT estimated acceptable reliability by obtaining values below the established thresholds (CV < 7.5 %; ICC > 0.75; SEM < 10% of mean) for all muscle groups for

endomorph and ectomorph somatotype groups when measured with B-mode ultrasound. The triceps brachii exceeded the CV threshold for reliability, the hamstring exceeded the CV threshold and failed to meet an ICC above 0.75, and the soleus exceeded the CV and SEM thresholds and failed to meet an ICC above 0.75 all in the mesomorph group. The SDDs in the mesomorph group were also consistently higher. This indicates that to ensure a real change in scores within this group when using two experimenters, the mesomorph group would require a greater increase in MT than the other two somatotype groups. Inter-tester values show good agreement between the two experimenters used in this particular study for the majority of locations, although it is recommended that inter-tester reliability is established when different researchers are included in the study.

Test-retest reliability for MT also estimated acceptable reliability by obtaining values below the established thresholds for all muscle groups for endomorph and ectomorph somatotype groups when measured with B-mode ultrasound. The triceps brachii exceeded the CV threshold for reliability, the hamstring failed to meet an ICC above 0.75, and the soleus exceeded the CV and SEM thresholds all in the mesomorph group. The SDDs in the mesomorph group were also consistently higher in test-retest measures. As such, even when one measurer undertakes the ultrasound assessments, a real change may only be detected in the mesomorph group with a greater increase in MT compared to the endomorph and ectomorph groups. Test-restest reliability demonstrated CV and ICC values similar to those already demonstrated in the literature. In particular, the bicep CV in the current study was lower (3.39%) than that demonstrated in the study by Reimers *et al.* (1993) of 7.4% but may be a result of improvements in technology in the past 25 years such as the resolution of ultrasound images. Test-restest ICC values were similar in the current study to those examined in the standing position in the paper by Thoirs and English (2009). They found that test-retest reliability was higher in the standing position compared to the recumbent position, although in results similar to this study they found a lower ICC for the posterior thigh (hamstring) site of 0.70 (in this study it was 0.74 for the mesomorph group). It may be, then, that those who have larger muscle mass may present with less reliable measurements in the standing position as muscle contraction may influence this parameter. Participants should be instructed to stand as relaxed as possible when having such measurements taken.

For PA, acceptable reliability was not reported for any location for any somatotype group for PA due to failure to meet the three previously reported criteria. For example, all CV values were considerably higher than the pre-determined threshold of 7.5 % (31.7-135.0 %) When interpreting

the ICCs, the only value falling into the 'good' range was the gastrocnemius in the mesomorph group (0.78) for inter-tester reliability and the hamstring in the ectomorph group (0.75) for test-retest reliability. Test-retest ICCs were at the lower end of the range demonstrated in a systematic review by Kwah and colleagues (2013) (0.51-1.00) although CVs far exceeded the range indicated by the same paper (2.1-13.5%). The previous authors also indicated a high degree of inter-rater reliability in their review for PA with an ICC of 0.80 in direct contrast to our study. The poor reliability of PA measures in the current study is further supported by observations that PA normally changes in the region of 2-6^{o} (Kawakami *et al.,* 1995; Aagaard *et al.,* 2001; Alonso-Fernandez et al., 2018) in training studies. A high proportion of the SDDs in the current study were higher than these values indicating that a real change may only be detected if changes higher than those seen in previous research were observed. In their discussion, Kwah *et al.* (2013) indicated that high degree of reliability in PA measures were still possible even in the absence of formal ultrasound training. Despite this, it has been suggested that consistent measures will only be possible if the probe is aligned at exactly the same angle on each occasion (Azizi and Roberts, 2009; Stark and Schilling, 2010). In fact, even a 15^{o} deviation of probe orientation from the true fascicle plane has been shown to produce error in PA of 23% (Bernard *et al.,* 2009). Low reliability of PA in this study is likely to have resulted in part from probe orientation errors. Given that ultrasound sessions measured a few weeks apart are likely to result in changes of PA (Kwah *et al.,* 2013) it would seem inappropriate to use this measure as an estimate of changes due to training interventions.

4.6 Conclusion

This study has demonstrated that somatotype can be accurately classified in simplified form when TEMs are low. This error needs to be kept as low as possible when calculating somatotype and may need to be even lower than that stated by ISAK (Stewart *et al.*, 2011) for accreditation of the most technically skilled anthropometrists. If a participant is mis-categorised into the incorrect somatotype group, observations between groups could be mis-represented. For this reason, simplified categorisation should be used in group comparison studies. The results from this part of the study fail to reject the hypothesis that 95% confidence intervals would be the low in the researcher measures. The TEMs should remain as low as possible and categorisation should be in simple form.

Muscle thickness is reliable for endomorph and ectomorph groups and can be used to demonstrate a true value or change in value post-exercise. Reliability of mesomorphy tricep brachii, hamstring and soleus sites has not been estimated in the current study and so comparison results for these

muscles in this group should be approached with caution. In general, MT can be used in future investigations with this untrained male population to indicate differences between groups or changes in muscle thickness. Reliability was poor for PA in this study and is unlikely to offer a clear indication of change in muscle architecture in response to exercise. These results fail to reject the hypothesis, with muscle thickness demonstrating good reliability but with PA demonstrating poor reliability.

Chapter 5: Study 3. The relationship between somatotype, muscle architecture and salivary hormones at rest and post resistance exercise.

5.1 Abstract

This study assessed the relationship between muscle thickness (MT) and somatotype ratings, and investigated differences in salivary hormones before and after an acute bout of resistance exercise. Thirty untrained males (mean somatotype: 10 Endomorphs 5.6-4.8-1.5; 10 Mesomorphs 3.0-5.9-1.6; 10 Ectomorphs 2.1- 2.7-4.5) were assessed for MT using B-Mode ultrasound. Participants provided a pre- and post-exercise saliva sample following a resistance training bout on two separate occasions. Testosterone (T) and cortisol (C) concentrations were assessed for test-retest reliability and compared between somatotype groups. MT was compared between somatotype groups and against somatotype ratings. There were significant (p<0.01) differences between mesomorphs and ectomorphs in MT at the bicep brachii (mean [SD] Mesomorphs 3.49 [0.16] cm; Ectomorphs 2.85 [0.07] cm) and biceps femoris (Mesomorphs 3.84 [0.27] cm; Ectomorphs 3.15 [0.10] cm). There were significant positive correlations between bicep brachii (r=0.49), biceps femoris (r=0.54), rectus femoris (r=0.54), and soleus (r=0.47) MT and mesomorphy rating (p<0.017). There were significant negative correlations between biceps femoris (r=-0.61), and rectus femoris (r=-0.54) MT and ectomorphy rating (p<0.017). Test-retest reliability for T and C concentration at pre- and post-exercise was good-excellent. There were no significant differences between somatotype groups in pre-exercise T and C concentration, T:C or in responses to resistance exercise (all p>0.05) . Greater MT in mesomorphic participants partly explains the higher level of strength performance previously demonstrated. Saliva T and C are both reliable but are not related to somatotype. Muscle size and strength development are unlikely to be related to differences in hormone concentrations between those of different somatotypes.

5.2 Introduction

The study in Chapter 3 of this thesis demonstrated an assoication between somatotype components and strength performance. In particular, mesomorphy rating was highly related to chest press and back squat strength, with the latter also being influenced by ectomorphy rating. Further research is required to understand some of the physiological mechanisms that contribute to the somatotype-strength relationship. Chapter 4 of this thesis established that TEM in anthropometrical measures need to remain low, and categorisation of somatotypes should be kept simple when making comparisons between somatotype groups in any measures. Strength output can also be determined by the architectural structure of muscle (Fukunaga *et al.,* 2001; Lieber, 2010), and some of the differences in architectural structure have been related to hormonal activity (Alen *et al.,* 1988; Kraemer *et al.,* 1990; Jensen *et al.,* 1991; Kraemer *et al.,* 1999). This study, therefore, will look to establish muscle architecture and hormonal activity differences between participants categorised into simple dominant somatotype groups (endomorphs, mesomorphs and ectomorphs).

Elements of somatotype are consistently linked to aspects of strength performance (Lewandowska *et al.,* 2011; Marta *et al.,* 2011). Early work indicated that the endo-mesomorphic physique was preferential for performance in strength and power tasks (Bale *et al.*, 1984; Quarrie *et al.*, 1996). Mesomorphy, in particular, is an indicator of physical robustness and so has a positive association with strength and motor performance (Malina and Bouchard, 1991). Since mesomorphy is a representation of musculo-skeletal robustness (Carter and Heath, 1990), the link between larger muscles and strength appears to be supported.

Studies have demonstrated a strong relationship between muscle size and aspects of strength performance (Siders *et al.,* 1993; Olds, 2001; Brechue and Abe, 2002; Patterson *et al.,* 2007; MacGillivray *et al.,* 2009; Saha, 2014). It is suggested that a larger muscle could contain more sarcomeres, and therefore have the ability to produce greater force output (Saha, 2014). Muscle size may, though, not be the only consideration, as various environmental and genetic factors could influence the function of muscle in a strength context (Huygens *et al.,* 2004).

Girth measurements in mesomorphs have been shown to be higher than in ectomorphs, but not significantly different from endomorphs (Bolunchuk *et al.,* 2000). Whilst a girth corrected for skinfold could be a surrogate measure for lean mass (and therefore muscle size) (Arazi *et al.*, 2013), it does

not directly measure the size of the muscle. It is not known whether there is a direct relationship between dominant somatotype and direct measures of muscle size.

Imaging techniques such as ultrasound have the ability to directly measure muscle thickness in those muscles close to the surface of the skin (Menon *et al.,* 2012). Muscle thickness has been demonstrated to accurately predict the cross-sectional area or size of various muscle groups (Sipila and Suominen, 1993; Abe *et al*., 1997; Miyatani *et al.,* 2004; Akagi *et al.,* 2010; Abe *et al.,* 2016). Authors have taken different approaches to ultrasound measurement depending on the population group under investigation with those investigating elderly or clinical populations often measuring total muscle mass in regions such as the anterior mid-thigh (Fukumoto *et al.,* 2012; Menon *et al.,* 2012; Takai *et al.,* 2013). Those studies with a trained or younger population often pinpoint specific muscles such as the triceps brachii or rectus femoris (Blazevich and Giorgi, 2001, Brechue and Abe, 2002).

Changes in hormone concentration and activity are considered necessary for adaptation at the muscular level (Beaven *et al.*, 2008). In particular, testosterone response to exercise may, in part, influence the individual hypertrophic adaptation (Alen *et al.,* 1988; Kraemer *et al.,* 1990; Jensen *et al.,* 1991; Kraemer *et al.,* 1999). Therefore, research studies often measure hormonal responses to exercise routines in order to understand the potential for muscle hypertrophy (Hakkinen and Pakarinen 1993; Kraemer *et al.,* 1995; Gotshalk *et al.,* 1997; Ahtiainen *et al.,* 2003b; Kraemer *et al.,* 2006; Crewther *et al.,* 2008; Migiano *et al.,* 2009; Ronnestad *et al.,* 2011). However, some research has suggested no relationship between increases in testosterone concentration and hypertrophic or strength development (Wilkinson *et al.,* 2006; West *et al.,* 2009; West and Phillips, 2012). Methodological differences surrounding hormone analysis (plasma or saliva, assay technique), exercise protocols (mode, intensity, duration) and participant population may result in conflicting findings surrounding the hormone-response to exercise literature.

Athletic populations consistently demonstrate acute hormonal responses to resistance exercise protocols (Kraemer *et al.,* 1990; Gothshalk *et al.,* 1997; Ahtiainen *et al.,* 2003;). However, the pattern of exercise often determines the magnitude and timing of the response such that hormonal responses to resistance exercise are protocol-specific (Kraemer *et al.,* 2001; Kraemer and Ratamess,

2005). Crewther and colleagues (2008) indicated that differences in hormonal response were likely due to load intensity, rest periods and technique rather than volume factors. In particular, those exercise protocols that involve hypertrophy-targeting loads and rest periods are more likely to increase testosterone and cortisol concentrations (Hakkinen and Pakarinen, 1993; Kraemer *et al.,* 1993; Smilios *et al.,* 2003; Zafeiridis *et al.,* 2003). The hormonal responses to exercise in untrained individuals varies from the response seen in trained athletes (Kraemer *et al.,* 1998; Ahtiainen *et al.,* 2003). In untrained males, protein metabolism, muscle hypertrophy and strength gains may not be related to elevations in hormone concentration (Wilkinson *et al.,* 2006; Buresh *et al.*, 2009; West *et al.,* 2009; West *et al.,* 2010). However, it has been suggested that hormonal responses to resistance exercise can be enhanced in the untrained population in order to assist in muscle hypertrophy in the early phases of a resistance programme (Hickson *et al.,* 1994; Kraemer *et al.,* 1998; 1999; Bird *et al.*, 2006; Izquierdo *et al.,* 2009). Given the differences observed in hormonal responses based on training status, it is important to consider this factor in the sampled population.

The hormonal response to resistance exercise is not homogenous, with large inter-individual differences when undertaking a similar exercise protocol (Hakkinen *et al.*, 1987; Kraemer *et al.,* 1990; Jensen *et al.,* 1991; Kraemer *et al.,* 2001; Di Luigi *et al.,* 2003; Smilios *et al.,* 2003; Beaven *et al.*, 2008; Crewther *et al.,* 2009). It has been suggested previously that these different responses may reflect gene-related variation in stress response (Tsopanakis *et al.,* 1994), possibly reflecting a link between hormonal responses and other genetically mediated factors such as body composition (Smith, 2003). Research in adolescent soccer players demonstrated significant correlations between hormonal responses to a maximal exercise test and some somatotype groups (Handziska *et al.,* 2015) demonstrating a possible link between somatotype and hormonal response. However, this link has not yet been demonstrated in adults.

Hormonal responses to exercise can be measured via plasma analysis or through using saliva samples. The advantage of using saliva to analyse hormonal responses to exercise is that it is noninvasive and therefore can cause less stress to the participant than blood sampling (Beaven *et al.*, 2008; Crewther *et al.,* 2008). Research has shown that the bioactive component of testosterone interacts with androgen receptors to bring about changes at the muscular level (Ahtiainen *et al.,* 2003; Kraemer and Ratamess, 2005), and so the positive link between saliva hormone concentration and free plasma hormone concentration (bioactive component) is important (Vining and McGinley, 1987; Kraemer *et al.,* 2001;) in order to assess any meaningful changes via saliva analysis. Research

has also demonstrated that sensitivity to change following exercise protocols is greater in saliva-based hormones than those analysed via plasma (Crewther *et al.,* 2010). Reliability literature surrounding hormones in saliva generally focuses on the reliability of the assays used during the analysis stage. These assays are usually tested for intra- and inter-assay CV, with those for cortisol ranging from 3.2-7.5% (intra), and 3.2-10.0% (inter). Testosterone assay analysis demonstrates similar reliability with CVs ranging from 2.6-13.1% (intra) and 2.5-10.0% (inter) (Gonzalez-Bono *et al.,* 2002; Beaven *et al.*, 2008; Crewther *et al.,* 2010; Hough *et al.,* 2013; Schultheiss, 2013). There are few studies that look at the between session variability of saliva testosterone at rest and post resistance-exercise in order to be able to establish the true magnitude of any change. High test-retest reliability will help to establish any real differences in the exercise induced change in testosterone and cortisol between somatotype groups.

The aim of this study was to establish measures of muscle architecture of participants with different somatotypes, and to investigate if there are any relationships between the somatotype and the measures of muscle architecture. It was hypothesised that mesomorphs would have a significantly larger muscle thickness compared to the other somatotype groups, reflective of the superior strength observed in those high in mesomorphy rating. This study further aimed to investigate if there are any differences in salivary hormones at rest and in response to resistance exercise between somatotype groups. The study will establish reliability of these saliva markers between sessions and further contextualise the saliva-hormone response (testosterone and cortisol) to resistance exercise in untrained participants. It was hypothesised that test-restest reliability would be high and that this would allow for appropriate comparison of hormone concentrations between somatotype groups. It was hypothesised that there would be a significant difference in baseline hormone concentration and its response to resistance exercise between somatotype groups.

5.3 Methods

5.3.1 Participants

Thirty untrained, from a resistance perspective, but physically active males (see Table 5.1 for participant characteristics) were recruited to the study. They were recruited on the basis that they considered themselves untrained (i.e. had not taken part in resistance training on a regular [two or more times] weekly basis for the past six month). The study received approval from the Faculty Ethics Committee (see Apppendix 2a). All participants were provided with an information sheet and consent form (Appendix 2b and c), detailing the purpose of the study and their right to withdraw at

any time without any disadvantage of any kind, prior to the start of testing. As such participants provided written informed consent to participate in the study.

Table 5.1: Study participant characteristics (mean ± SD)

	Age (y)	Stature (m)	Body Mass (kg)	Endomorphy	Mesomorphy	Ectomorphy
Endomorphs (N = 10)	25 ± 6	1.82 ± 0.06	93.5 ± 18.9	5.6 ± 1.4	4.8 ± 1.6	1.5 ± 1.1
Mesomorphs (N = 10)	24 ± 4	1.76 ± 0.06	80.3 ± 9.22	3.3 ± 1.3	5.9 ± 1.5	1.6 ± 1.0
Ectomorphs (N = 10)	21 ± 2	1.84 ± 0.07	68.7 ± 7.0	2.1 ± 0.3	2.7 ± 0.7	4.5 ± 0.7

5.3.2 Research Design

The research study adopted a quantitative group comparisons approach using primary data collection. Participants were recruited initially using purposive sampling for the initial body composition assessment, with the requirement that they be untrained (no planned and structured resistance exercise programme undertaken or in the last 6-months but could still be physically active). Following anthropometric data collection and calculation of somatotype, participants were assigned to a group on the basis of being dominant (one half unit higher) in that somatotype. If they were not considered dominant then they were excluded from the study. Participants were tested on two separate mornings with at least one week between sessions. Participants were requested to attend testing fully hydrated, having eaten 1-2 hours prior to testing and having abstained from alcohol, caffeine or cigarette smoking within 12 hours of testing, and strenuous exercise within 24 hours of testing. Muscle architecture measures were taken in triplicate at each site for each participant by two investigators with basic training in analysis of ultrasound images on each of the two visits. A priori sample size calculation (G* Power) was used to determine the participant number required. Utilising previous published research on muscle thickness measured using ultrasound, in particular mean values and variance and Cohen's (1988) guidelines for effect sizes, a mean f value of 0.6 was entered. A sample size of 30 participants (10 in each of 3 groups) was determined as appropriate for a calculated power of 0.80.

5.3.3 Anthropometric Procedures

Participants' anthropometric profiles were measured by a Level 3 ISAK anthropometrist using ISAK protocols (Stewart *et al.,* 2011) and somatotype calculated in line with the methods outlined for somatotype in Chapter 3 (section 3.3.4 Somatotype assessment). Participants were then assigned to

their dominant category based on being one half unit higher in that category. Mean technical error of measurement for skinfolds was 2.5% and for all other measures was 0.3%. Mean TEM for somatotype was 0.1 somatotype units, and could have led to 10 (1 mesomorph, 2 ectomorphs, 7 endomorphs) participants being miscategorised (although dominant number was still within that category for each of these participants, maintaining validity of the study).

5.3.4 Muscle architecture procedures

Participants underwent ultrasound assessment of upper (bicep brachii and triceps brachii) and lower (biceps femoris, rectus femoris, gastrocnemius, soleus) body muscle groups using B-Wave ultrasound (u smart 3300, Terason, USA) with a linear array probe (4 MHz wave frequency). Images were taken in the transverse plane (see Figure 4.2 in Chapter 4 for image) with the participants standing with weight evenly distributed on both legs. Ultrasound images were taken at the marked locations for triceps and biceps skinfold site, front thigh skinfold site and a marked tracked posteriorly from this onto the mid-hamstring, and at a mark tracked posteriorly from the medial calf skinfold site. Images were analysed for muscle thickness using the in-built callipers. Muscle thickness was assessed as the distance from the adipose-tissue–muscle interface and muscle–bone interface at the middle of the image (Abe *et al.,* 1994).

5.3.5 Saliva samples

Following the anthropometric measures, participants were asked to refrain from drinking water for 10 minutes before providing a resting 3.5 ml saliva sample into a plastic vial via passive drool. Samples were frozen in a bench-top freezer prior to assay analysis. The samples were then thawed and centrifuged before being tested in duplicate for both testosterone (T) and Cortisol (C) concentration using enzyme immunoassay kits (Salimetrics, UK).

Following collection of baseline saliva samples, participants completed a predicted-1RM assessment of chest press, bicep curl and back squat in order to prescribe the subsequent resistance exercise. The assessment followed ACSM guidelines (2017) for determination of 1RM but allowed participants to lift a weight that equated to between 5 and 10 repetitions of each exercise. An initial load was placed on the bar and the participant was required to complete as many repetitions as possible. Following a rest period of 3-5 minutes, the load was increased by 5-10% and the exercise repeated. When the participant could only complete between 5-10 repetitions of that exercise the load on the

bar was recorded alongside the number of repetitions. Where possible, this load was determined within 4 trials. Predicted 1RM was determined using a table published in Baechle and Earle (2008, p.397). On two further separate occasions, separated by at least one week, participants returned to the laboratory to undertake a resistance training exercise bout consisting of the same exercises performed for the 1RM but prescribed at 65% of 1RM for 10 repetitions and 3 sets of each exercise with 3 minutes rest between sets as per ACSM (2009) recommendations for novice to intermediate individuals. Following the entire resistance-training bout, a further saliva sample was taken from the participant 15 minutes post exercise and treated as per the previous methodology.

5.3.6 Statistical Analysis

Participants were grouped according to dominant somatotype, and muscle thickness and saliva hormone concentration (T, C and T:C) pre, post and exercise induced change assessed for normality via skewness and kurtosis Z scores and Shapiro-Wilk statistical test (IBM SPSS Statistics v24). All data was normally distributed (between -1.96 to +1.96 Z score and $p > 0.05$ for Shapiro-Wilk test; Field, 2009) apart from muscle thicknesses in the biceps brachii and gastrocnemius for the ectomorph group, biceps femoris in the mesomorph group, and pre-exercise C in the mesomorph group and pre-exercise T:C in the endomorph group. However, given the robustness of ANOVA to these violations (Blanca *et al.,* 2017*)* and the lack of platykurtosis in the data set, the following analysis was undertaken.

One-way ANOVAs were conducted to identify any between-group differences in muscle thickness. Significance was set at $p > 0.05$ and effect size (η_p^2) calculated. An effect size was considered to be large if above 0.14 (Cohen, 1973). Tukey HSD post hoc tests were used to demonstrate any significant relationships in muscle thickness between the different somatotype groups.

A Pearson correlation analysis was carried out by plotting individual somatotype rating scores for each somatotype element against muscle thickness. To account for multiple comparisons and the chance of a type I error, a Bonferroni correction was applied to the p value (divided by 3 to acknowledge the 3 somatotype rating scores) such that this was set at $p < 0.017$.

Reliability statistics (CV, ICC, SEM and SDD) were calculated for cortisol and testosterone concentration as per the equations provided in Chapter 4 (Section 4.3.2.4 Statistical analysis) for test-restest reliability across the two sessions. Based on the range of values outlined in the introduction of this chapter, a measure was considered reliable if the CV fell below 10% (the highest value for test-retest CV saliva assay in the literature being 10%). Individual assay CV was also assessed and reported for the duplicate assay analysis. Although literature indicates a higher range of values for intra-test reliability (up to 13.13%), the threshold of 10% remained for assay analysis to maintain study consistency. Based on the guideance from Koo and Li (2016), if a hormone measure had an ICC 0.75-0.90 it had good reliability, anything above 0.90 was considered excellent. The reliability criterion for SEM was set at < 10% of the mean value. The SDD is presented in units of the specific measurement. It was not used to determine reliability per se, but as an indicator for the magnitude of measurement required to determine a real change.

Two-way repeated measures ANOVAs were used to analyse T,C and T:C over time and between the three somatotype groups. Significance was set at $p < 0.05$ and effect size (η_p^2) calculated. Post hoc contrasts were used to demonstrate where any significant differences were located. An effect size was considered to be large if above 0.14 (Cohen, 1973).

5.4 Results

The somatotype means for each group are shown in Figure 5.1. SADs ranged from 0.8-4.9 (endomorph group), 0.7-3.3 (mesomorph group) and 0.4-1.5 (ectomorph group). SAMs were 1.9 (endomorph group), 2.0 (mesomorph group), 0.9 (ectomorph group).

5.4.1 Muscle thickness

There was a significant difference in bicep brachii MT between somatotypes $F(2, 27) = 5.648$, $p < 0.01$, $\eta_p^2 = 0.29$ (CI = 0.05-0.46) (Figure 5.2). The Tukey HSD post hoc test indicated mesomorphs had a significantly higher bicep brachii MT than ectomorphs ($p < 0.01$) .

There was a significant difference in biceps femoris MT between somatotypes $F(2, 27) = 5.504$, $p < 0.01$, $\eta_p^2 = 0.29$ (CI = 0.05-0.45) (Figure 5.2). The Tukey HSD post hoc test indicated mesomorphs had a significantly higher MT than ectomorphs ($p < 0.01$).

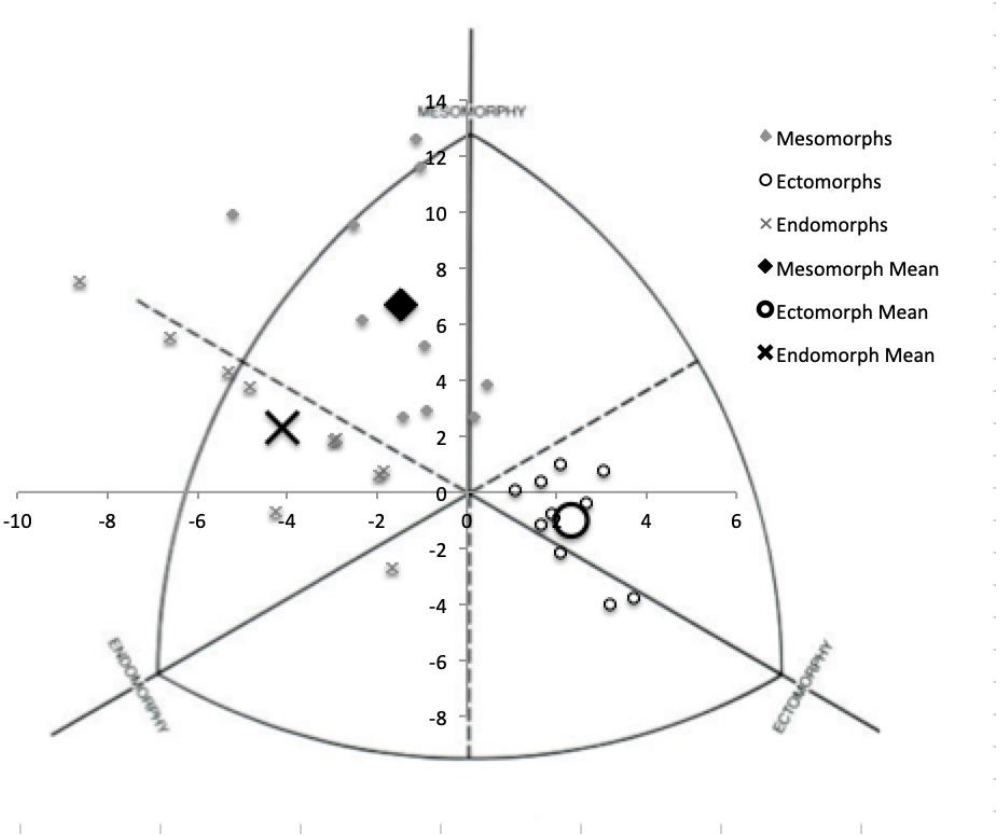


Figure 5.1: Somatotype distribution of study participants with group means represented by highlighted symbols.

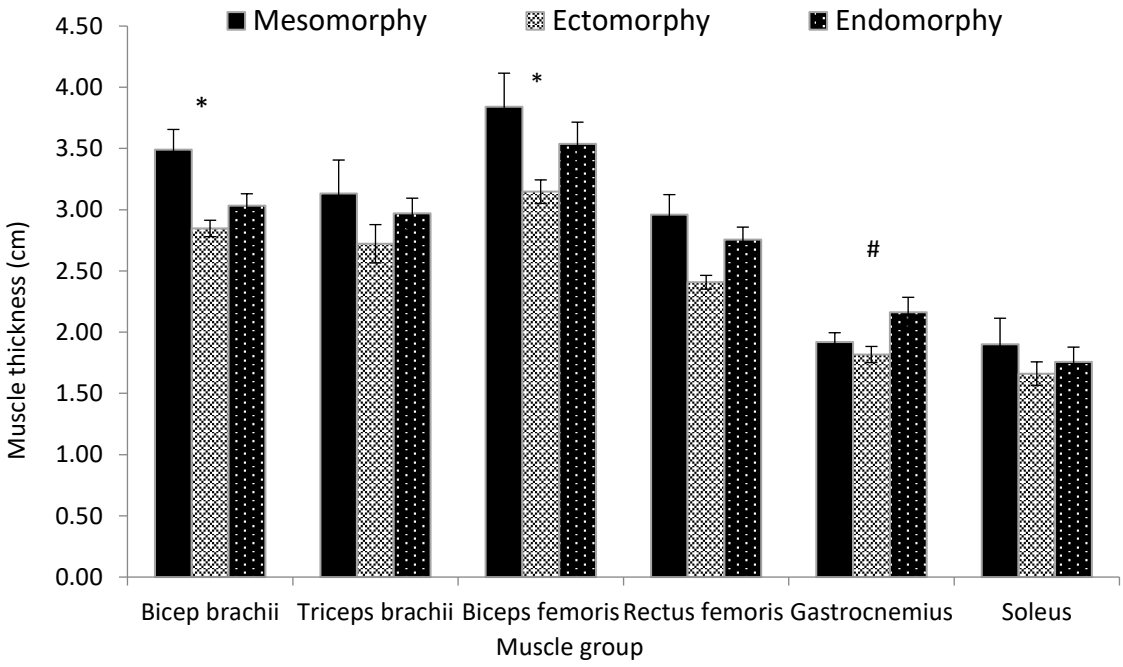


Figure 5.2: Mean muscle thickness values grouped according to somatotype

** significant difference between mesomorphy and ectomorphy, p <0.01;*
 # significant difference between ectomorphy and endomorphy, p < 0.05.

There was a significant difference in gastrocnemius MT between somatotypes F (2, 27) = 3.666, p <0.05, η_p^2 = 0.21 (CI = 0.01-0.38) (Figure 5.2). The Tukey HSD post hoc test indicated endomorphs had a significantly higher MT than ectomorphs (p < 0.05).

There were no other significant differences between somatotype groups and muscle thickness measures (p > 0.05), although medium-large effect sizes were found for all muscle groups (η_p^2 triceps brachii = 0.15 [CI = 0-0.31]; rectus femoris = 0.19 [CI = 0-0.36]; soleus = 0.11 [CI = 0-0.27]).

5.4.1.1 MT Correlations

A significant positive correlation was observed between mesomorphy and bicep brachii MT (r = 0.49, p < 0.017) (Table 5.2). There was no significant correlation between endomorphy or ectomorphy and bicep brachii MT (p > 0.016).

There was no significant correlation between any of the somatotype ratings and triceps brachii MT (p > 0.017) (Table 5.2).

A significant positive correlation was observed between mesomorphy and biceps femoris MT (r = 0.54, p < 0.017) (Table 5.2). A significant negative correlation was observed between ectomorphy and biceps femoris MT (r = -0.61, p < 0.017) (Table 5.2). There was no significant correlation between endomorphy and biceps femoris MT (p > 0.017).

A significant positive correlation was observed between mesomorphy and rectus femoris MT (r = 0.54, p < 0.017) (Table 5.2). A significant negative correlation was observed between ectomorphy and rectus femoris MT (r = -0.54, p < 0.017) (Table 5.2). There was no significant correlation between endomorphy and rectus femoris MT (p > 0.017).

A significant positive correlation was observed between endomorphy and gastrocnemius MT (r = 0.50, p < 0.017) (Table 5.2). There was no significant correlation between mesomorphy or ectomorphy and gastrocnemius MT (p > 0.017).

A significant positive correlation was observed between mesomorphy and soleus MT (r = 0.47, p < 0.017) (Table 5.2). There were no significant correlations between either endomorphy or ectomorphy and soleus MT (p > 0.017).

Table 5.2: Pearson correlation results between muscle thickness and somatotype components.

Muscle	Somatotype Component	Pearson's r	P value
Bicep brachii	Endomorphy	-0.07	0.703
	Mesomorphy	0.49	0.006#
	Ectomorphy	-0.42	0.020
Triceps brachii	Endomorphy	-0.05	0.806
	Mesomorphy	0.28	0.139
	Ectomorphy	-0.41	0.024
Biceps femoris	Endomorphy	0.24	0.210
	Mesomorphy	0.54	0.002#
	Ectomorphy	-0.61	0.000#
Rectus femoris	Endomorphy	0.09	0.641
	Mesomorphy	0.54	0.002#
	Ectomorphy	-0.54	0.002#
Gastrocnemius	Endomorphy	0.50	0.005#
	Mesomorphy	0.22	0.238
	Ectomorphy	-0.39	0.031
Soleus	Endomorphy	0.15	0.445
	Mesomorphy	0.47	0.008#
	Ectomorphy	-0.34	0.067

Significant correlation: # p ≤0.016 (Bonferonni adjusted)

5.4.2 Testosterone

There was no significant main effect in testosterone concentration for somatotype ($F[2,18] = 1.99$, $p > 0.05$, $\eta_p^2 = 0.18$ [CI = 0.00-0.37]) or time ($F[1,9] = 3.97$, $p > 0.05$, $\eta_p^2 = 0.31$ [CI = 0.00-0.56]), and no significant interaction effect ($F[2,18] = 3.43$, $p > 0.05$, $\eta_p^2 = 0.28$ [CI = 0.00-0.46]) (Figure 5.3).

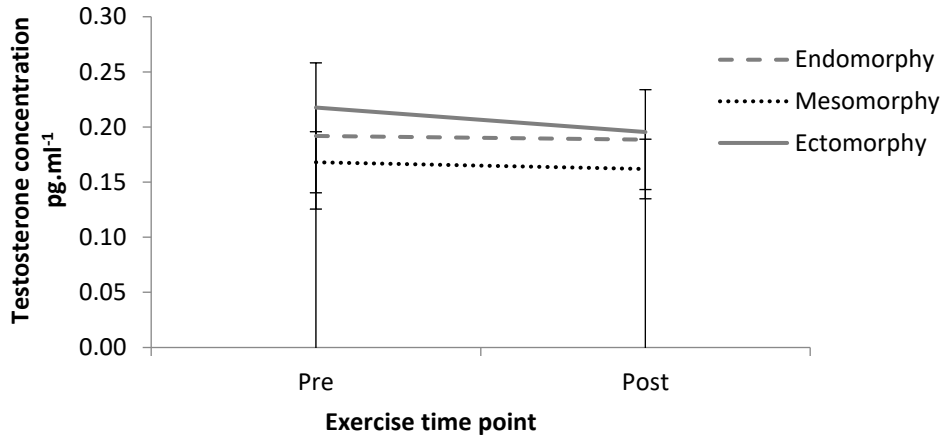


Figure 5.3: Mean testosterone concentration pre and post exercise between somatotypes.

5.4.3 Cortisol

There was no significant main effect in cortisol concentration for somatotype (F[2,18] = 3.31, p > 0.05, η_p^2 = 0.27 [CI = 0.00-0.45]). There was a significant decrease in cortisol concentration over time (F[1,9] = 78.66, p < 0.01, η_p^2 = 0.90 [CI = 0.69-0.93]), but no significant interaction effect (F[2,18] = 1.59, p > 0.05, η_p^2 = 0.15 [CI = 0.00-0.34]) (Figure 5.4).

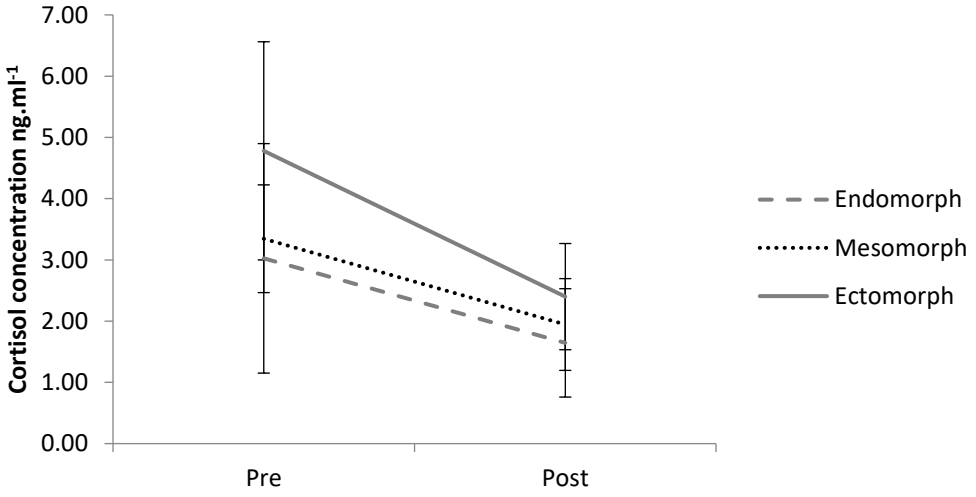


Figure 5.4: Mean cortisol concentration pre and post exercise between somatotypes.

5.4.4 Testosterone: Cortisol

There was no significant main effect in T:C for somatotype (F[2,18] = 2.57, p > 0.05, η_p^2 = 0.22 [CI = 0.00-0.41]). There was a significant increase in T:C over time (F[1,9] = 45.87, p < 0.01, η_p^2 = 0.84 [CI = 0.54-0.90]), but no significant interaction effect (F[2,18] = 0.96, p > 0.05, η_p^2 = 0.10 [CI = 0.00-0.27]) (Figure 5.5).

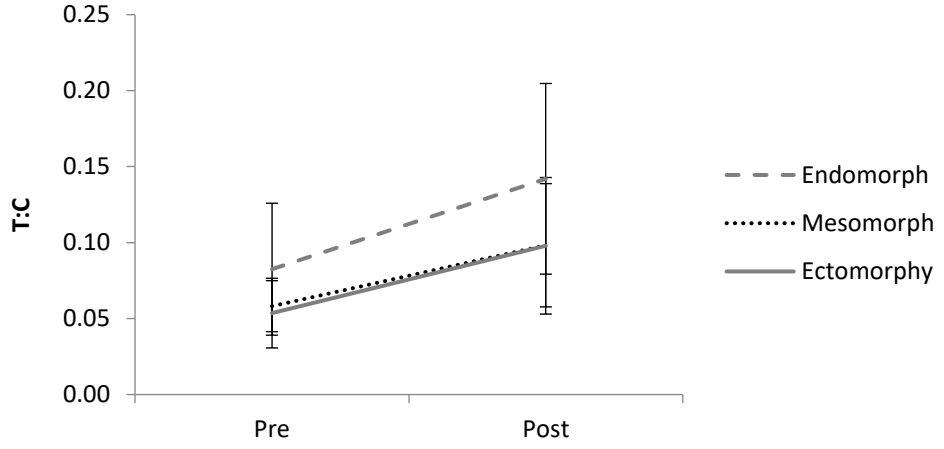


Figure 5.5: Mean T:C pre and post exercise between somatotypes.

5.4.5 Reliability

Duplicate assay CV values for both testosterone (3.15%) and cortisol (3.43%) analysis for all samples were under the 10% threshold set. Test-retest reliability for both time points for testosterone and cortisol met all set reliability criteria; CV values were all below the 10% threshold set, all ICCs exceeded the 0.9 excellent threshold, and SEMs range from 2.1-5.9% of the mean (below 10% set). The highest SDDs for testosterone were in the mesomorph group at baseline and the endomorph group post exercise, and for cortisol in the ectomorph group at baseline. SDDs were similar for all groups for cortisol concentration post exercise.

Table 5.3: Test-retest reliability of saliva testosterone and cortisol measures at baseline and post-exercise.

Hormone	Time point	Somatotype	CV (%)	ICC	SEM (T pg.ml^{-1}; C µ.dL^{-1})	SDD (T pg.ml^{-1}; C µ.dL^{-1})
Testosterone	Baseline	Endomorph	2.15	1.00	4.76	13.20
		Mesomorph	3.96	0.96	6.68	18.51
		Ectomorph	2.52	1.00	5.22	14.47
		Overall	*2.87*	*0.98*	*5.55*	*15.39*
	Post-exercise	Endomorph	3.98	0.98	6.97	19.33
		Mesomorph	3.15	0.98	5.20	14.40
		Ectomorph	3.23	0.99	6.39	17.71
		Overall	*3.45*	*0.98*	*6.19*	*17.15*
Cortisol	Baseline	Endomorph	4.28	1.00	0.01	0.03
		Mesomorph	3.53	0.99	0.01	0.03
		Ectomorph	2.86	1.00	0.01	0.04
		Overall	*3.56*	*1.00*	*0.01*	*0.03*
	Post-exercise	Endomorph	4.72	0.99	0.01	0.02
		Mesomorph	2.87	0.99	0.01	0.02
		Ectomorph	2.77	1.00	0.01	0.02
		Overall	*3.45*	*0.99*	*0.01*	*0.02*

5.5 Discussion

The aim of this study was to establish if there are any differences in measures of muscle architecture of participants with different somatotypes, and to understand any relationship between salivary hormones and somatotype. This could, in part, explain the differences in strength output observed in Chapter 3 of this thesis. The current study suggests that there is a significant difference in MT between somatotypes with mesomorphs generally having larger muscle thickness values. This reflects the greater strength output demonstrated by this group in Chapter 3. There is also a significant relation between MT and mesomorphy and ectomorphy ratings. There were no significant differences in salivary testosterone or cortisol either at baseline or following a resistance training

session between somatotype groups. These latter measures were established as reliable during the current research.

5.5.1 Muscle Thickness

There were significant differences between mesomorphs and ectomorphs in bicep brachii and biceps femoris MT, and between endomorphs and ectomorphs in gastrocnemius MT. Although no other significant differences were found, large effect sizes indicate the results could still hold some practical significance (Kirk, 1996). Effect sizes indicate the degree to which the results diverge from the null hypothesis (that there will be no significant difference between somatotype groups in muscle thickness) (Vacha-Hause and Thompson, 2004). In general, mesomorphs had the highest mean MT values (apart from gastrocnemius, where endomorphs had the highest) whilst ectomorphs had the lowest. This is similar in nature to the relationship between girth measurements and somatotypes established by Bolunchuk *et al.* (2000). Since muscle thickness is a predictor of muscle size (Sipila and Suominen, 1993; Abe *et al.,* 1997; Miyatani *et al.,* 2004; Akagi *et al.,* 2010; Abe *et al.,* 2016), the current study indicates that mesomorphs have significantly larger bicep brachii and bicep femoris muscles. There is a well-established positive relationship between muscle size and function (Patterson *et al.,* 2007; MacGillivray *et al.,* 2009) that would help explain the superior strength performance demonstrated by mesomorphs in the initial study of this thesis (see Chapter 3). In fact, as MT is a contributor measurement to muscle mass, and muscle strength is primarily determined by muscle mass (Huygens *et al.,* 2004) then it follows that mesomorphs would have superior strength ability compared to ectomorphs in particular.

The endomorph group demonstrated an advantage in gastrocnemius MT compared to the ectomorph group. Takai *et al.* (2013) acknowledged the presence of non-contractile tissue such as intramuscular adipose in ultrasonic measurements of MT. It may be that, in the gastrocnemius measurements in particular, more of this intramuscular adipose is measured for the endomorph group that contributes to their larger measurements. It should also be noted that test-retest reliability in study 2 for the gastrocnemius measures in the endomorph group was generally lower than in the other two groups and so the difference here may also be representative of some error in measurement.

The correlation analysis demonstrated positive relationships between MT and mesomorphy rating and negative relationships between MT and ectomorphy rating. This aspect of the results shows this study supporting past research that established relationship between these ratings and strength performance, further demonstrating the link between muscle function and size (Huygens *et al.,* 2004; Patterson *et al.,* 2007; MacGillivray *et al.,* 2009). Mesomorphy and ectomorphy are strongly governed by genes (Peeters *et al.,* 2007) and so potentially demonstrate a strong genetic predisposition towards muscle size and function. The lower heritability estimate of endomorphy means that dominance in this group is likely more a reflection of diet and physical activity habits than of genetic predisposition to adipose accumulation. As such, the inclusion of this group may mask the true relationship between somatotype and muscle size. This is further supported by a general lack of relationship between endomorphy and muscle thickness in the current study. It appears that the somatotype strength relationship is, in part, due to muscle size.

5.5.2 Salivary hormones

There was no statistical difference in saliva hormone concentration or saliva hormone response between somatotypes. In fact, even within somatotype groups the saliva hormone concentrations were heterogeneous, indicating that factors other than physique mediate this aspect of physiology. This heterogeneous response is similar to that observed in studies investigating the hormonal response to resistance exercise amongst trained participants (Hakkinen and Pakarinen, 1987; Kraemer *et al.,* 1990; 2001; Smilios *et al.,* 2003).

There was a significant decrease in cortisol (mean ± [SD] 41.7 ± [20.2] %) and increase in T:C (mean ± [SD] 87.2 ± [89.2] %) due to the exercise protocol amongst the entire population. Previous research has demonstrated that the athletic population demonstrate acute hormonal responses to resistance exercise protocols (Kraemer *et al.,* 1990; Gothshalk *et al.,* 1997; Ahtiainen *et al.,* 2003), although the relationship amongst untrained participants is less clear. In the current study the general trend was for saliva testosterone concentration to decrease post-exercise (mean ± [SD] 3.7 ± [11.7] %), which is in contrast to the increase demonstrated in previous research (Kraemer *et al.,* 1990; Smilios *et al.,* 2003; Beaven *et al.*, 2008) and from serum testosterone measurements (Kraemer *et al.,* 1991; Hakkinen and Pakarinen, 1993; Gothshalk *et al.,* 1997). Decreases in testosterone concentration similar to that shown in the current have been shown in hypertrophy-type protocols (Bosco *et al.,* 2000; Kraemer *et al.,* 2001). Similarly, whilst the current study demonstrated a decrease in cortisol concentration post exercise similar to that shown in Beaven *et al.* (2008), this is in contrast to results

demonstrated in other hypertrophy protocols (Hakkinen and Pakarinen, 1993; Gothshalk *et al.,* 1997; Kraemer *et al.,* 1998;). It would appear, therefore, that hormonal responses to resistance exercise are highly reliant on study participant and resistance exercise characteristics. Even given standardisation, it would still appear that the hormonal response to resistance exercise is determined on an individual participant level. Research has suggested the hormonal response could be genetically mediated (Tsopanakis *et al.,* 1994), although this study would suggest this genetic pathway could be very different to that which governs physique.

Muscular adaptation may be mediated by hormonal changes (Beaven *et al.*, 2008), although given the heterogeneous response in the current study population the exact nature of this mediation remains unclear. The results from this study support the uncertainty that surrounds the biological role of hormone changes in response to resistance exercise (West and Phillips, 2012). Acute hormonal responses to resistance training may have an important regulatory mechanism surrounding protein metabolism during recovery (Kraemer *et al.,* 1992; Kraemer and Ratamess, 2005). In the current study, it may be that the change in T:C is a demonstration of this regulation, with a conservation of T concentration compared to C concentration, prioritising protein anabolism during recovery from this particular resistance protocol. Although, protein metabolism, muscle growth and strength may not be governed by hormones elevated physiologically in untrained participants (Wilkinson *et al.,* 2006; Buresh *et al.*, 2009; West *et al.,* 2009; 2010).

A correlation has previously been established between T concentrations at baseline and changes in isometric strength (Ahtiainen *et al*., 2003), although we observed no such relationship between those predisposed to superior baseline strength performance (mesomorphs) and baseline testosterone concentration. Given that the paper by Ahtiainen and colleagues (2003) also found no significant change in hormonal concentration over a 21-week resistance training period, it is unlikely that hormones will mediate the training response demonstrated by those in different somatotype groups.

The immunoassay kits demonstrated excellent reliability in duplicate measures with the CVs for testosterone and cortisol (<3.5%) being much better than those previously reported in immunoassay kits by Crewther *et al.* (2010; <9%) or in radioimmunoassay analysis by Schultheiss (2013; <13.2%). To date there is scarce research on test-restest reliability of salivary testosterone and cortisol.

However, this research demonstrates that at both baseline (pre-exercise) and post-exercise reliability is good to excellent. Saliva analysis in response to an exercise session should be representative of changes in the hormone response to exercise and demonstrate any differences in the individual response to that particular exercise regime.

5.5.3 Limitations

Although research suggests that muscle mass is closely related to muscle strength (Huygens *et al.,* 2004), it should be noted that muscle mass and function themselves are influenced by a wide range of environmental and genetic factors. Whilst this study suggests that somatotype and MT are closely related, it is possible that other factors such as nutrition and previous physical activity may have influenced MT (Volek, 2004) and therefore not all mesomorphs may have superior muscle size.

The current study only investigated one aspect of biological variance in response to resistance exercise (saliva hormone response). Muscular strength performance is reliant on a combination of biological and behavioural variables (Marta *et al.,* 2011) that may further be unrelated to somatotype. However, if the hormonal-mediated responses are not different between somatotypes further research is required to investigate other physiological responses to resistance exercise such as mechanical and haemodynamic responses.

5.6 Conclusion

The results of this study suggest that there is a clear relationship between somatotype and muscle thickness, with mesomorphs having the highest values and ectomorphs the lowest. The results of this study demonstrate no consistent relationship between endomorphy rating and muscle thickness, with the impact of environmental factors on this somatotype rating potentially masking a dominance in mesomorphy or ectomorphy. The superior muscle size in mesomorphic participants partly explains the higher level of strength performance previously demonstrated in those participants and may put mesomorphic participants at an advantage with respect to the adaptations associated with resistance training. The results fail to reject the hypothesis that mesomorphs would have a large muscle thickness. Further research is needed to assess whether mesomorph participants do respond more favourably to resistance training programmes.

The saliva hormone response to the current resistance exercise protocol was heterogeneous across the study population, with no significant differences between somatotypes. The heterogeneous response is similar to that observed in other studies and appears to represent a genetic difference in the way hormones respond to resistance exercise in different participants. The hypothesis that there would be a significant difference between baseline hormones and in the way they respond to an acute bout of resistance exercise between somatotype groups was rejected. Saliva testosterone and cortisol are both reliable and can be used to demonstrate a true value or change in value post-exercise, which results in a failure to reject the hypothesis of good test-retest reliability in this measure. In the absence of any clear patterns related to somatotype it would appear that muscle size, and possible strength development, are unlikely to be related to differences in hormone concentrations between those of different somatotypes.

Preface to Chapter 6

The studies presented in this thesis demonstrate that somatotype is related to strength output (Chapter 3) and muscle thickness (Chapter 5). In particular, it appears that mesomorphs have a superior muscle strength and larger muscles thicknesses, whilst ectomorphs occupy the other extreme. The results of the studies also indicate that the endomorphy rating of somatotype is not related to strength output, and that endomorphic participants do not differ significantly in muscle thickness from mesomorphs or ectomorphs. As endomorphic participants are highly influenced by adipose tissue, and muscle thickness measures are not able to separate intramuscular adipose stores from contractile tissue, it is possible that endomorphic muscles are not representative of functioning contractile tissue alone. Combined with the strong influence of environment on endomorphic ratings and the lack of clear relationship between endomorphy and strength output, there is a strong rationale to exclude endomorphic participants from further study in this thesis.

As mesomorphs have a superior strength output and initial muscle thickness, this may predispose them to advantage in a resistance training regime, where in untrained participants one might expect to see increases in both strength and muscle size (hypertrophy). As such, it seems logical to determine the influence of dominant somatotype on responses to resistance training in the untrained population.

Chapter 6: Study 4. The influence of somatotype on responses to resistance training in untrained participants

6.1 Abstract

This study assessed somatotype-related differences in response to resistance training in untrained participants. Sixteen males from ectomorphic (mean somatotype 1.9-3.3-4.2) and mesomorphic (3.8-5.8- 2.1) somatotypes completed an 8-week resistance training and an 8-week control period in a cross-over design. Baseline measures of strength (10 repetition maximum [RM] back squat, close-grip bench press, bicep curl), muscle thickness (MT), EMG and NIRS measures in the bicep brachii (BB), triceps brachii (TB), rectus femoris (RF) and biceps femoris (BF) were recorded and repeated at week 8. For the back squat, ectomorphs demonstrated a significantly greater increase in 10-RM than mesomorphs (26.4%; $p < 0.05$, $\eta_p^2 = 0.78$) during training. Mesomorphs (14.9%) experienced a larger increase in TB MT than ectomorphs (2.6%) during training ($p < 0.01$, $\eta_p^2 = 0.42$). Mesomorphs (11.2%) also experienced a larger increase in BF MT compared to ectomorphs (3.4%) during training ($p < 0.01$, $\eta_p^2 = 0.37$). Significant positive correlations were observed between mesomorphy rating and change in BB (r = 0.50), TB (r = 0.69), and BF (r = 0.75) MT. Significant negative correlations were

observed between ectomorphy rating and change in BB (r = -0.65), TB (r = -0.76), and BF (r = -0.72) MT. EMG or NIRS results could not clearly explain the differences observed. In the current study, mesomorphs demonstrated greater hypertrophy than ectomorphs over the training period. Ectomorphs developed similar or greater (back squat) strength improvements to mesomorphs. Areas for future inquiry are suggested to examine the varying responses seen by different somatotypes to resistance training.

6.2 Introduction

The research in this thesis has demonstrated a relationship between somatotype, strength (Chapter 3) and muscle size (Chapter 5). However, little is known about this relationship and the training response. Since loading programmes induce changes in muscle size and contractile components in skeletal muscle (Haddad and Adams, 2002; Bird *et al.*, 2005; Holm *et al.,* 2008), there is a possibility that these changes are mediated in some way by components of somatotype (particularly mesomorphy and ectomorphy).

When an individual undergoes a period of resistance training, they will experience adaptations in their muscular characteristics that predominantly relate to neurological activation, and changes in muscle architecture such as increase in size (Kraemer and Ratamess, 2000). However, the nature of these adaptations is heterogeneous across the population and may be reliant on several factors such as genetics, prior training status and nutritional status. Given the relationship between somatotype and strength demonstrated in Chapter 3 and the superior muscle size demonstrated by mesomorphs in Chapter 5, there could be a relationship between somatotype and the responses to a resistance programme.

Early research in somatotype demonstrated that university athletes dominant in mesomorphy had an advantage in improving anaerobic power when undertaking an 8-week sport specific training period (Schreiber, 1973). Research has also identified that mesomorphy and ectomorphy are positively associated with changes in sprint speed in prepubescent children when undertaking an 8-week training programme (Marta *et al.,* 2013). These changes are likely due to adaptations in neurological muscle function at this age as opposed to muscle growth (Ramsay *et al.,* 1990; Ozmum *et al.,* 1994), and so the impact of somatotype on hypertophic response remains unknown. Some research has demonstrated that previous training status has little impact on the relationship between somatotype components and leg power (Saha, 2014) or strength performance (Marta *et al.,* 2011) in young college students and children, offering a suggesting that training response may not be different between somatotypes. However, this was a suggestion based on reported levels of training rather than an actual intervention. Further, Marta *et al.* (2011) demonstrated that somatotype was a more significant determinant of strength performance in children than physical activity levels, offering support as to the nature of the somatotype-training relationship.

The nature of somatotype adaptation during training has generally received little attention. When testing 15 male football (soccer) players from La Liga during the competition phase, Casajus (2001) demonstrated that there was no significant difference in somatotype components over a 6-month period, despite a significant decrease in sum of 6 skinfolds, indicating somatotype components to be relatively stable. The relative stability of somatotype over a long period of physical activity and conditioning holds promise for a consistent predictor of training response to allow for individually-tailored exercise prescription if a somatotype-training response relationship is established.

Whilst some adaptations could relate to the participant, others will be reliant on the components of the training programme and so it is important that all participants complete a training programme with the same frequency and loading characteristics.

6.2.1 Strength Development

Research has clearly demonstrated a link between training status of the population and resistance training response, with untrained participants demonstrating the greatest improvements in strength development (Hakkinen *et al.,* 1987; Ahtiainen *et al.,* 2003b; Peterson *et al.,* 2005; ACSM, 2009; Williams *et al.,* 2017). Untrained participants are also unlikely to have had their somatotype altered through previous resistance training, and so are likely to be close to their genetic physique. Given that endomorphy is mediated by environmental influences (Peeters *et al.,* 2007), and that the findings of Chapter 5 demonstrated the strongest differences and relationships to be between ectomorphs and mesomorphs, endomorphs will be excluded from the study design.

Improvements in strength have been recognised following periods of resistance training by measuring isotonic 1RM (Wilkinson *et al.,* 2006), maximal concentric 1RM (Ahtiainen *et al.,* 2003; 2016), concentric-eccentric 1RM (West and Phillips, 2012), and maximal voluntary contraction (MVC) (Tan, 1999). These observations have often been supported by examining signals from electromyography assessments during the movements that can provide an indication of activation and fatigue during the exercise (Hakkinen *et al.,* 1987; Aagaard, 2003; Gentil *et al.,* 2017). Previous research has identified that changes in EMG signal value are not directly related to changes in strength (Hakkinen *et al.,* 1987), although the values gained from EMG assessment can give an indication of any changes in the amount of muscle activity resulting from a training programme (McBride *et al.*, 2003). Resistance training protocols of 12 - 14 weeks have demonstrated increases

in EMG amplitude alongside increases in the rate of force development involving heavy loads (Van Cutsem *et al.*, 1998), and relatively light loads at 30-40% 1RM (Aagaard *et al.,* 2002). An 8-week resistance training protocol demonstrated significant changes in biceps brachii and brachioradilais EMG amplitude in opposing directions following bicep curl activity (Oliviera and Goncalves, 2009). The biceps brachii saw a decline in EMG amplitude, whilst the brachioradialis demonstrated an increase. Other researchers have noted a decline in the integrated EMG signal in the leg extensors (vastus lateralis and rectus femoris) with systematic progressive strength training over 8 weeks in healthy young men (Thorstensson *et al.,* 1976). A change in EMG amplitude may be observed over an 8-week period, although the direction of this change is not obvious.

6.2.2 Hypertrophy

The link between muscle size and strength performance is generally well established (Siders *et al.,* 1993; Olds, 2001; Brechue and Abe, 2002; Patterson *et al.,* 2007; MacGillivray *et al.,* 2009; Saha, 2014). Research also demonstrates that muscle size increases in response to resistance training, although the time course of this adaptation is often debated (Phillips, 2000; Abe *et al.,* 2005; Seynnes *et al.,* 2007; DeFreitas *et al.,* 2011). A control or normal activity period is often omitted from these studies, so the true rate of muscle hypertrophy cannot be easily established. Muscle hypertrophy has been measured in resistance training studies using anthropometry (Cureton *et al.,* 1988; McLester *et al.,* 2000; Arazi, Damirchi and Asadi, 2013; Coratella and Schena, 2016), computerised tomography (CT) scans (Cureton *et al.,* 1988; DeFreitas *et al.,* 2011) and ultrasound (Blazevich and Giorgi, 2001, Brechue and Abe, 2002; Seynnes *et al.,* 2007; Ogasawara *et al.,* 2012; Damas *et al.,* 2015), although the timing and magnitude of these measurements remains equivocal.

6.2.3 Metabolic response and hypertrophy

The adaptive response of a muscle to resistance training can also be metabolic in nature. The increase in intramuscular mechanical pressure created during a movement against resistance can lead to reduced local blood flow and transient hypoxia (Spiering *et al.,* 2008). Studies that have artificially reduced blood flow through vascular occlusion methods have demonstrated a link between blood flow reduction and the anabolic response such that the hypoxic environment appears to be favourable for hypertrophic mechanisms to occur (Viru *et al.,* 1998; Takarada *et al.,* 2000; Abe *et al.,* 2005). Hoffman and colleagues (2003) further demonstrated a link between muscle oxygenation status and growth hormone response in local tissue during resistance exercise. Measurement of the muscle blood flow and oxygenation status of the exercising muscles over the

course of a resistance training study could indicate underlying mechanisms behind hypertrophic responses.

Local muscle blood flow can be measured via invasive techniques such as dilution and washout, or non-invasive techniques at the surface of the skin (Sako *et al.,* 2001; Casey *et al.*, 2008). During exercise, invasive methods are often useful and require less technical skill than some of the surface imaging equipment, but the expertise required and intrusiveness of the technique results in it being a less attractive option for immediate results (Casey *et al.*, 2008). Doppler ultrasound has proven useful in the measurement of blood velocity during both static (Shoemaker *et al.,* 1996; Walloe and Wesche, 1988) and dynamic exercise (Tschakovsky *et al.*, 1995; Radegran, 1997; Schrage *et al.*, 2004; Wray *et al.,* 2007; Parker *et al.,* 2008; Wilkins *et al.,* 2008), although this is generally submaximal in nature and the technique is limited in the information it can provide about the oxygenation status of a muscle. Near infrared spectroscopy (NIRS) has been adapted more recently to measure blood flow in localised muscles (Hachiya *et al.*, 2008). Near infrared light is absorbed differently by oxygenated and deoxygenated haemoglobin resulting in an absorption pattern that can estimate blood flow (Casey *et al.* , 2008). NIRS is non-invasive and so can be used to measure blood flow during dynamic activities (Rundell *et al.*, 1997; Szemdra *et al.,* 2001). It has been validated as an appropriate technique for measuring blood flow (Homma *et al.,* 1996) and oxygenation (Hamaoka *et al.,* 1996). Previous research has demonstrated NIRS measurements are more sensitive to changes in local muscle blood flow and oxygenation characteristics than more central measures such as phosphorous magnetic resonance spectroscopy (P-MRS) (Sako *et al.,* 2001) and the Fick method (Van Beekvelt *et al.,* 2001). Thus, its use to measure the metabolic changes observed during dynamic resistance exercise appears to be warranted. NIRS appears to have established good test-retest reliability in various muscles during dynamic activities (Van Beekvelt *et al.,* 2002; Pereira *et al.*, 2005; Tanimoto and Ishii, 2006).

6.2.4 Measurement of hypertrophic response

Many of the adaptive responses to resistance exercise are reliant on the parameters of the training programme. Several authors have reported increases in strength and measures of muscle size (CSA, circumference, thickness) in resistance training programmes lasting anywhere from 4 - 24 weeks (O'Hagan *et al.,* 1995; Carroll *et al.,* 1998; Abe *et al.,* 2000; Tarpenning *et al.,* 2001; Campos *et al.,* 2002; Ahtiainen *et al.,* 2003a, b; Wilkinson *et al.,* 2006; Ahtiainen *et al.,* 2016). It would however appear that hypertrophy can only be seen when training programme duration is 8 weeks or more

(Wilkinson *et al.,* 2006). Initial improvements in strength performance are often purported to be a result of neurological adaptations (Sale, 1988; Moritani and deVries, 1979) with this observation supported by increases in lower limb EMG activity in the initial stages of resistance programmes (Hakkinen *et al.,* 1998; 2000a, b; 2001a, b; Holviala *et al.,* 2010; Karavirta *et al.,* 2011; Holviala *et al.,* 2012; Mikkola *et al.,* 2012; Walker *et al.,* 2014). However, there is a suggestion that muscle hypertrophy measures in many studies may lack sensitivity and that hypertrophy could occur sooner than is currently reported (Phillips, 2000). Developments in technology and more sensitive measurement instruments such as ultrasound and CT have demonstrated significant muscle growth from resistance training in as little as 2 - 3 weeks (Abe *et al.,* 2005; Seynnes *et al.,* 2007; DeFreitas *et al.,* 2011; Ogasawara *et al.,* 2012).

6.2.5 Components of training programmes

Equivocal results suggest that strength improvements can plateau at around 10 weeks (Graves *et al.,* 1988), or can be continuing to improve after this point (Hickson, 1980; Abe *et al.,* 2000) into a resistance programme, although a recent meta-analysis suggested that longer duration studies result in greater gains in maximal strength (Williams *et al.,* 2017). Increases in strength have been shown as early as two weeks (lower body) and six weeks (upper body) in untrained men undertaking a resistance training programme for three days per week (Abe *et al.,* 2000).

Training programmes normally consist of 2-3 sessions per week (Braith *et al.,* 1989; Dudley *et al.,* 1991; Carroll *et al.,* 1998; Tarpenning *et al.,* 2001; Campos *et al.,* 2002; Ahtiainen *et al.,* 2003; Paulsen *et al.,* 2003; Wilkinson *et al.,* 2006; Ahtiainen *et al.,* 2016), although in research they have included up to 5 (West and Phillips, 2012). Three sessions per week has been suggested to be an effective initial frequency (ACSM, 2009). A meta-analysis by Rhea and colleagues (2003) determined that there was a dose-response relationship between training frequency and strength development, concluding that 3 days per week was optimal for untrained participants.

A meta-analysis using effect size data by Peterson and colleagues (2005) has shown that untrained individuals get maximal strength gains from exercises at 60% 1 repetition maximum (RM), 3 days per week with a mean volume of 4 sets per muscle group. However, daily variation in strength output of 10 - 20% can result in mis-representation of training load if load is prescribed via a fixed percentage of 1RM (Poliquin, 1988). It has been suggested that working to a set load for a range of repetitions

will offer more control for meeting the targeted training zone (Hoeger *et al.,* 1990). This approach would also negate the need for regular 1RM testing since load can be increased when participants exceed the prescribed repetition range (Tan, 1999). ACSM (2009) suggest that the load should be increased by 2 - 10% when the participant can perform 1 - 2 repetitions more than that prescribed. Untrained individuals are purported to experience maximal strength gains at a mean training intensity of around 12RM (Rhea *et al.,* 2003). In general, multiple sets are considered preferable to single sets (Rhea *et al.,* 2002; 2003; Munn *et al.,* 2005). Rest intervals are recommended as 2 - 5 minutes for strength-focused resistance programmes (Baechle *et al.*, 2000; ACSM, 2009). It is suggested that this is due to the ability to maintain a higher training intensity when sufficient recovery is given, versus minimal recovery (Robinson *et al.,* 1995; Kraemer, 1997; Richmond and Godard, 2004; Willardson and Burkett 2005; 2006a, b).

Improvements in muscle strength and muscle morphology appear to be greatest when both concentric and eccentric movements are included (Colliander and Tesch, 1990; Dudley *et al.,* 1991; O'Hagan *et al.,* 1995). The debate surrounding single and multiple joint exercises is more complex, with both providing pros and cons; single joint exercises pose less injury risk (ACSM, 2009) (and therefore may be more appropriate for novice trainers), but multiple joint exercises create greater demands neurologically (Kraemer *et al.,* 2002) and often result in greater strength gains (ACSM, 2009). However, it has also been suggested that single joint exercises may demonstrate hypertrophy sooner than multi-joint ones due to less neurological adaptation (Rutherford and Jones, 1986; Chilibeck *et al.,* 1998). Many programmes often include both, with multiple joint exercises being performed first (Kraemer, 1983) due to their higher energy expenditure demands than single joint exercises (Hickson *et al.,* 1984). This has further been suggested to create a greater training stimulus and therefore potentially increase training outcomes (Kraemer and Fleck, 1988; Sforzo and Touey, 1996). Movement velocity is generally recommended to be slow-moderate (2s concentric, 4s eccentric) for novice trainers to ensure good technique (ACSM, 2009).

The aim of this study was to examine the differences in adaptation to an 8-week resistance training programme between dominant mesomorph and dominant ectomorph untrained participants. It was hypothesised that the mesomorph group would experience a significantly greater magnitude of hypertrophy than the ectomorph group. This would also coincide with a significantly greater strength development in the mesomorph group compared to the ectomorph group. It was further

hypothesised that there would be significant differences in EMG amplitude and NIRS parameters both at rest and change over the training programme between the somatotype groups.

6.3 Methods

6.3.1 Participants

Sixteen male participants from ectomorphic (n=8) and mesomorphic (n=8) physiques respectively were recruited to this study. Participant characteristics are shown in Table 6.1. Participants were untrained novice resistance exercisers (no prior resistance training of 2 or more sessions a week for the previous 6 months) with no pre-existing injury or illness that would prevent them from taking part in the programme. The study received approval from the Faculty Ethics Committee (see Appendix 3a). All participants were provided with an information sheet and consent form, detailing the purpose of the study and their right to withdraw at any time without any disadvantage of any kind, prior to the start of testing (see Appendix 3b and c). As such participants provided written informed consent to participate in the study.

Table 6.1: Participant characteristics (mean ± standard deviation)

	Ectomorphs	**Mesomorphs**	**Overall**
Age (years)	25.6 ± 6.3	28.1 ± 7.1	26.9 ± 6.6
Height (m)	1.84 ± 0.05	1.79 ± 0.06	1.81 ± 0.06
Body Mass (kg)	69.3 ± 5.9	85.8 ± 23.2	77.6 ± 18.4
Endomorph rating	1.9 ± 0.5	3.8 ± 2.4	2.9 ± 2.0
Mesomorph rating	3.3 ± 0.4	5.8 ± 2.2	4.5 ± 2.0
Ectomorph rating	4.2 ± 0.3	2.1 ± 1.3	3.2 ± 1.4

6.3.2 Research Design

The research study adopted a quantitative group comparisons approach using primary data collection. Participants were recruited initially using purposive sampling for the initial body composition assessment, with the requirement that they be untrained (no planned and structured exercise programme undertaken or in the last 6-months but could still be physically active). Following anthropometric data collection and calculation of somatotype, participants were assigned to a group on the basis of being dominant (one half unit higher) in that somatotype. If they were not considered dominant, or they were a dominant endomorph then they were excluded from the study. The study involved a randomised cross-over design such that half of the participants started with the resistance training period, and half with the normal activity before completing the other condition following a 4-week wash out period (Kubo *et al.,* 2010). Participants were requested to

attend all testing and supervised training sessions fully hydrated, having eaten 1-2 hours prior and having abstained from alcohol, caffeine or cigarette smoking within 12 hours of testing, and strenuous exercise within 24 hours of testing and training. A priori sample size calculation (G* Power) was used to determine the participant number required. Utilising Cohen's (1988) guidelines, a large effect size (η_p^2 of 0.14) resulted in an f value of 0.4 being entered. Further data entered into the software included 2 groups, 2 repeated measures, and a correlation among repeated measures of 0.74 (based on the lowest test-retest correlation value for MT in Chapter 4). A sample size of 10 participants (5 per group) was determined as appropriate for a calculated power of 0.87.

6.3.3 Anthropometric measures

Somatotype dominance was determined by assessing each participant for their anthropometric profile. Anthropometric profiles were measured by a Level 3 ISAK anthropometrist using ISAK protocols (Stewart *et al.,* 2011) and somatotype calculated in line with the methods outlined for somatotype in Chapter 3 (section 3.3.4 Somatotype assessment). Mean TEM for skinfolds was 2.5 % and for all other measures was 0.2 %. Mean TEM for somatotype was 0.1 somatotype units, and could have led to 4 (3 mesomorphs and 1 ectomorph) participants being miscategorised based on the 95% confidence intervals for their somatotype ratings (although dominant number was still within that category for each of these participants, maintaining validity of the study).

6.3.4 Protocols

Participants were assigned to a 16-week cross over training programme with a 4-week wash-out after 8 weeks. During one 8-week period participants completed a novice resistance training programme (with permission to continue any non-resistance based physical activity they were currently undertaking) or continued with their normal activity regime, crossing over after 12 weeks (8 weeks training plus 4 week wash-out). The 4-week wash out was selected on the basis of prior research demonstrating a reduction in muscle CSA back to baseline following this time course in a similar population (Kubo *et al.,* 2010). Baseline measures of anthropometry (in addition to those measures already taken for somatotype determination; bicep, iliac crest, subscapular, abdominal and front thigh skinfold) were taken for each participant following ISAK protocols (Stewart *et al.,* 2011). Participants underwent baseline ultrasound assessment of upper (bicep brachii [BB] and triceps brachii [TB]) and lower (rectus femoris [RF] and biceps femoris [BF]) body muscle groups using B-Wave ultrasound (u smart 3300, Terason, USA) with a linear array probe (4 MHz wave frequency). Images were taken in the transverse plane with the participants standing with weight

evenly distributed on both legs. Measures were taken three times on each location for each participant by the primary investigator. Ultrasound images were taken at the marked locations for triceps and biceps skinfold site, front thigh skinfold site and a marked tracked posteriorly from this onto the mid-hamstring. Images were analysed for muscle thickness using the in-built callipers. Muscle thickness was assessed as the distance from the adipose-tissue–muscle interface and muscle–bone interface at the middle of the image (Abe *et al.,* 1994).

Due to the experience of the participants, everyone took part in a familiarisation session involving some technique coaching for the four exercises to be prescribed in the programme; back squat, Nordic curl, close-grip bench press and alternate arm bicep curl. These four exercises were chosen as each targeted the muscles previously measured in Chapters 4 and 5, with good test-retest reliability being established for these muscle measurements in Chapter 4. Following this and on a separate occasion, a baseline 10 repetition maximum assessment was carried out on each participant for the exercises prescribed in the training programme. The assessment followed ACSM guidelines (2017) for determination of 1RM but allowed participants to lift a weight that equated to 10 repetitions of each exercise. The 10 RM is considered a valid load for the assessment of strength (Braith *et al.,* 1993; Hopkins *et al.*, 1999; Pereira and Gomes, 2001 Dohoney *et al.,* 2002), and is a valid assessment of the progression specific to the training programme in the current study (Boyer, 1990). An initial load was placed on the bar and the participant was required to complete as many repetitions as possible. Following a rest period of 3-5 minutes, the load was increased by 5-10% and the exercise repeated. When the participant could only complete 10 repetitions of that exercise the load on the bar was recorded alongside the number of repetitions. Where possible, this load was determined within 4 trials.

During each trial, wireless surface EMG (Trigno, Delsys, Boston, USA) and NIRS (Portalite, Artinis medical systems, Einsteinweg, The Netherlands) recordings were obtained from the dominant limb. Surface EMG activity was recorded from the BB, TB, RF and BF during the concentric and eccentric components of each exercise for the 10RM. After shaving, abrading and cleaning the skin with alcohol, the surface electrode was placed immediately superior to the NIRS probe, which was placed directly over the marked location (the same as the ultrasound recording sites in Chapter 4 minus the gastrocnemius and soleus) at each site, and in the middle of the muscle belly longitudinally. EMG signals were sampled at 2000 Hz. Signals were AD converted in real-time via the manufacturing software (EMGworks Acquisition v4, Delsys). Raw EMG signals were filtered using a 20-450 Hz

bandpass filter and rectified and root mean square (rms) converted for EMG amplitude (EMGwork Analysis v4, Delsys). Following positioning of the NIRS probes and EMG electrodes, the limb was lightly wrapped with a bandage to reduce light contamination to the NIRS and maintain electrode contact with the skin to reduce movement artifacts. NIRS measurements were continuously recorded throughout the exercise with the signal transmitted to a computer via Bluetooth and recorded using Oxysoft software. Oxyhaemaglobin (O2Hb), Deoxyhaemaglobin (HHb), total haemoglobin (THb), and tissue saturation index (TSI) were measured via the NIRS. Data sampling rate was set at 50 Hz and NIRS light wavelength set at 760-850 nm. NIRS data was smoothed through a Gaussian filter (Oxysoft, Artinis).

6.3.5 Training programme

After completion of baseline testing, participants began their respective 8-week training period. For the resistance training period all participants were assigned personalised programmes based on their baseline or post 4-week washout 10 repetition maximums. The programme involved a whole-body resistance programme using free weights and consisted of 4 sets of 10 repetitions of each exercise. When each participant could complete 1-2 more than the required repetition per set the load was increased by 2-10% depending on the target muscle group (ACSM, 2009). This was completed during three supervised sessions per week with 48 hours rest in between. Baseline measuring protocols were repeated post the final training session in week 8 or 9. All participants in the resistance training condition swapped over to the no exercise condition for the final 8 weeks and vice versa with the no training to the training group.

All participants supplied both an activity and food diary for the duration of the training programme and normal activity period. For the food diary, participants were asked to supply a minimum of 3 days per week (to include at least one weekend day) of accurate food and fluid consumption, including weights and cooking methods. The information from the food diaries was entered into Nutritics (Version 5.0, Nutritics University Edition) and average daily calorie consumption recorded. For the activity diary, participants were instructed to complete the diary for at least 3 days per week. This was based upon the activity record method of Bouchard and colleagues (1983) and included recording a numerical activity value for each 15 minute period over 24 hours. This was averaged into a daily activity value.

6.3.6 Statistical Analysis

Participants were grouped according to dominant somatotype (2 groups: mesomorph and ectomorph), and somatotype attitudinal distance (SAD), muscle thicknesses (BB, TB, RF, BF), 10 RM strength (for back squat, close grip bench press and bicep curl), corrected relaxed arm girth (relaxed arm girth minus triceps skinfold; CRAG) and corrected arm girth flexed and tensed (arm girth flexed and tensed minus triceps skinfold; CAGFT), EMG peak amplitude (PAm) and time to peak amplitude (TTP) for each muscle for each exercise, and change in NIRS measures for each muscle for each exercise at baseline and post 8-weeks for each condition (training or control) and average daily calorie consumption and activity value for each somatotype group in the training and control condition assessed for normality via skewness and kurtosis Z scores and Shapiro-Wilk statistical test (IBM SPSS Statistics v26). Data was normally distributed if it was between -1.96 to +1.96 Z score and $p > 0.05$ for Shapiro-Wilk test (Field, 2009). However, given the robustness of ANOVA to these violations (Blanca *et al.,* 2017) and the lack of platykurtosis in the data set, the following analysis was undertaken.

Three-way repeated measures ANOVAs with condition (control, training) and time (baseline, post) within-subject factors and somatotype (Ectomorph, Mesomorph) as a between-subject factor were applied to the SAD data, the strength data for each exercise (back squat, close grip bench press, bicep curl), each muscle thickness (BB, TB, RF and BF) and each anthropometric measure (corrected relaxed arm girth [CRAG] and corrected arm girth flexed and tensed [CAGFT]). Significance was set at $p < 0.05$ and effect size (η_p^2) calculated. An effect size was considered to be large if above 0.14 (Cohen, 1973). Pearsons correlations were used to compare change in MT (from 0-8 weeks) to ratings of mesomorphy and ectomorphy for all participants. To account for multiple comparisons and the chance of a type I error, a Bonferroni correction was applied to the p value (divided by 2 to acknowledge the 2 somatotype rating scores) such that this was set at $p < 0.025$.

Peak amplitude (PAm) and time to peak amplitude (TTP) for each repetition of each exercise was noted for the 10RM effort and averaged for each occasion. Three-way repeated measures ANOVAs with condition (control, training) and time (baseline, post) within-subject factors and somatotype (ectomorph, mesomorph) as a between-subject factor were applied to the PAm and TTP data for each muscle (BB, TB, RF and BF) during each relevant exercise (back squat, close grip bench press, bicep curl). Significance was set at $p < 0.05$ and effect size (η_p^2) calculated. Pearson correlation analysis was used to compare change in absolute strength to change in peak EMG amplitude for

each muscle (BB, TB, RF and BF) during each relevant exercise (back squat, close grip bench press, bicep curl). As these measures were assessed at 2 muscles per exercise a Bonferroni correction was applied to the p value such that this was set at $p < 0.025$.

Mean values for change from baseline (Δ) in O_2Hb, HHb, tHB and TSI were recorded for each muscle (BB, TB, RF and BF) during each relevant exercise (back squat, close grip bench press, bicep curl) from the NIRS. The baseline period required the participant to remain still for 5 seconds prior to performing the required movement, and exercising values had this baseline value subtracted from them. Three-way repeated measures ANOVAs with condition (control, training) and time (baseline, post) within-subject factors and somatotype (ectomorph, mesomorph) as a between-subject factor were applied to this data, and significance set at $p < 0.05$ and effect size (η_p^2) calculated.

Mean daily calorie consumption (kcal·kg body mass^{-1}) and mean daily activity intensity (AU) were analysed using a two-way ANOVA with condition (control, training) within-subject factor and somatotype (ectomorph, mesomorph) as a between-subject factor. Significance set at $p < 0.05$ and effect size (η_p^2) calculated. Mean training volume per session (kg) for the training condition was compared for the two somatotype groups via an independent samples t-test with significance set at $p < 0.05$.

6.4 Results

The somatotype means for each group are shown in Figure 6.1. SADs ranged from 1.4-5.8 (mesomorph group) and 0.5-1.2 (ectomorph group). SAMs were 3.0 (mesomorph group), 0.7 (ectomorph group). For the SAD, there was no significant main condition or time main effect ($p > 0.05$). There was a significant somatotype main effect ($F[1,14] = 16.11$, $p < 0.01$, $\eta_p^2 = 0.54$ [CI 0.18-0.69]) with the mesomorph group having a higher mean SAD compared to the ectomorph group. There were no significant interaction effects for SAD ($p > 0.05$; Table 6.2).

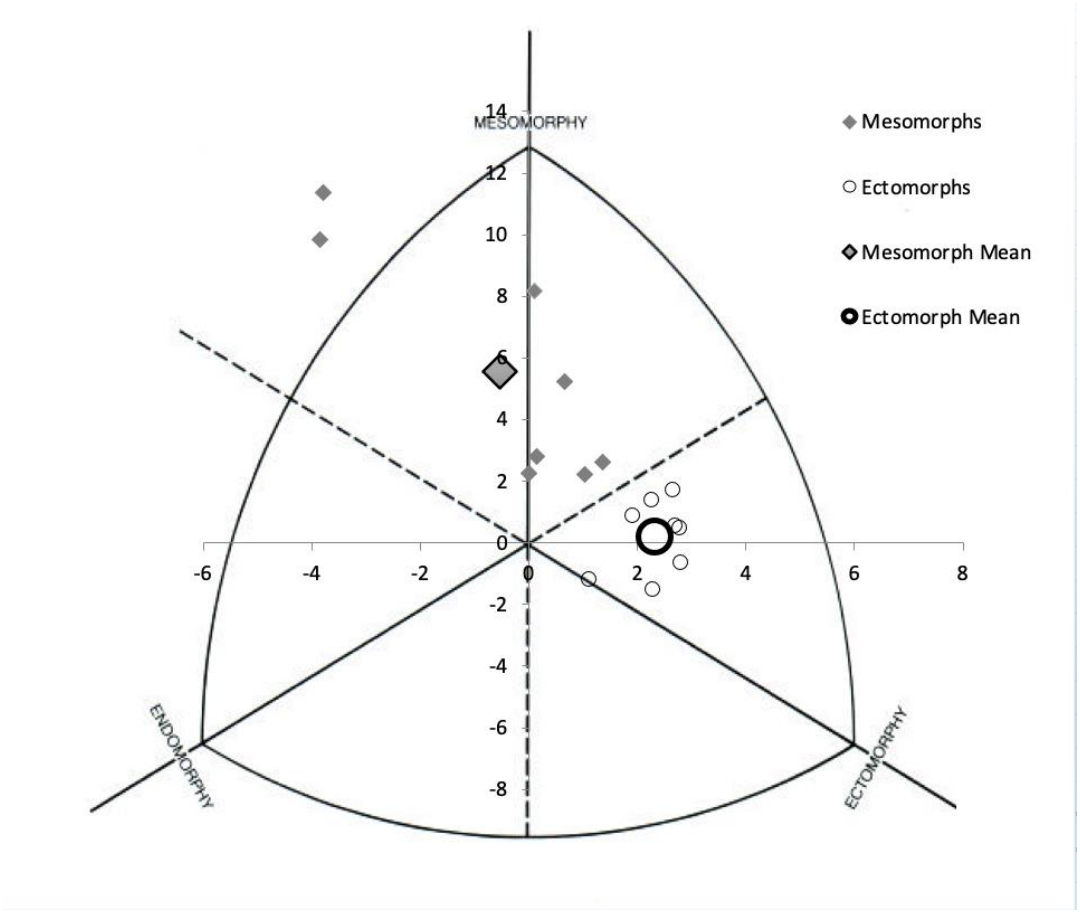


Figure 6.1: Distribution of somatotypes and somatotype group means

Table 6.2: Mean somatotype and somatotype attitudinal mean (SAM) for the different groups across the two conditions

		Mesomorphs (N = 8)				Ectomorphs (N = 8)			
		Endo	**Meso**	**Ecto**	**SAM**	**Endo**	**Meso**	**Ecto**	**SAM**
Training	**Pre**	4.2	5.8	2.0	3.0	1.9	3.2	4.3	0.7
	Post	4.2	5.9	1.9	3.0	1.9	3.3	4.2	0.7
Control	**Pre**	3.9	5.8	2.1	3.0	1.9	3.3	4.2	0.6
	Post	4.3	5.8	1.9	3.0	2.0	3.1	4.3	0.8

Endo = endomorphy rating; Meso = mesomorphy rating; ecto = ectomorphy rating; SAM = somatotype attitudinal mean, the mean of the individual somatotype attitudinal distances (SAD)

6.4.1 Strength

For the back squat, there was a significant time main effect ($F[1, 14] = 104.03$, $p < 0.01$, $\eta_p^2 = 0.88$ [CI 0.73-0.92]), with an overall increase in 10 RM back squat over time. There was also a significant condition main effect ($F[1, 14] = 17.81$, $p < 0.01$, $\eta_p^2 = 0.56$ [CI 0.21-0.71]). This is indicative of a higher overall 10 RM back squat mean in the training condition compared to the control (Figure 6.2). There was no significant somatotype main effect ($p > 0.05$). There was a significant time by condition

interaction effect (F[1, 14] = 207.21, $p < 0.01$, $\eta_p^2 = 0.94$ [CI 0.85-0.96]), demonstrated by a greater increase in 10 RM back squat strength over time in the training condition versus the control (Figure 6.2). Finally, there was a significant time by condition by somatotype interaction effect (F[1, 14] = 6.51, $p < 0.05$, $\eta_p^2 = 0.32$ [CI 0.03-0.54]). This is representative of a greater relative increase in 10 RM back squat for the ectomorph group in the training condition (70.0%) versus the mesomorph group (43.6%; Table 6.3). There was no significant interaction effect for time by somatotype or condition by somatotype ($p > 0.05$).

For the close grip bench press, there was a significant time main effect (F[1, 14] = 50.13, $p < 0.01$, $\eta_p^2 = 0.78$ [CI 0.53-0.86]), reflecting an overall increase in 10 RM performance over time (Table 6.3). There was no significant condition main effect for close grip bench press ($p > 0.05$; $\eta_p^2 = 0.22$ [CI 0.00-0.46]), nor a significant somatotype main effect ($p > 0.05$; $\eta_p^2 = 0.21$ [CI 0.00-0.45]). There was a significant time by condition interaction effect (F[1, 14] = 40.54, $p < 0.01$, $\eta_p^2 = 0.74$ [CI 0.47-0.83]) reflecting a greater increase in close grip bench press 10 RM over time in the training condition versus the control (Table 6.3). There were no other significant interaction effects for close grip bench press ($p > 0.05$), with the mesomorph group (33.5%) and ectomorph group (25.0%) demonstrating similar increases in 10 RM performance over the training programme (Table 6.3).

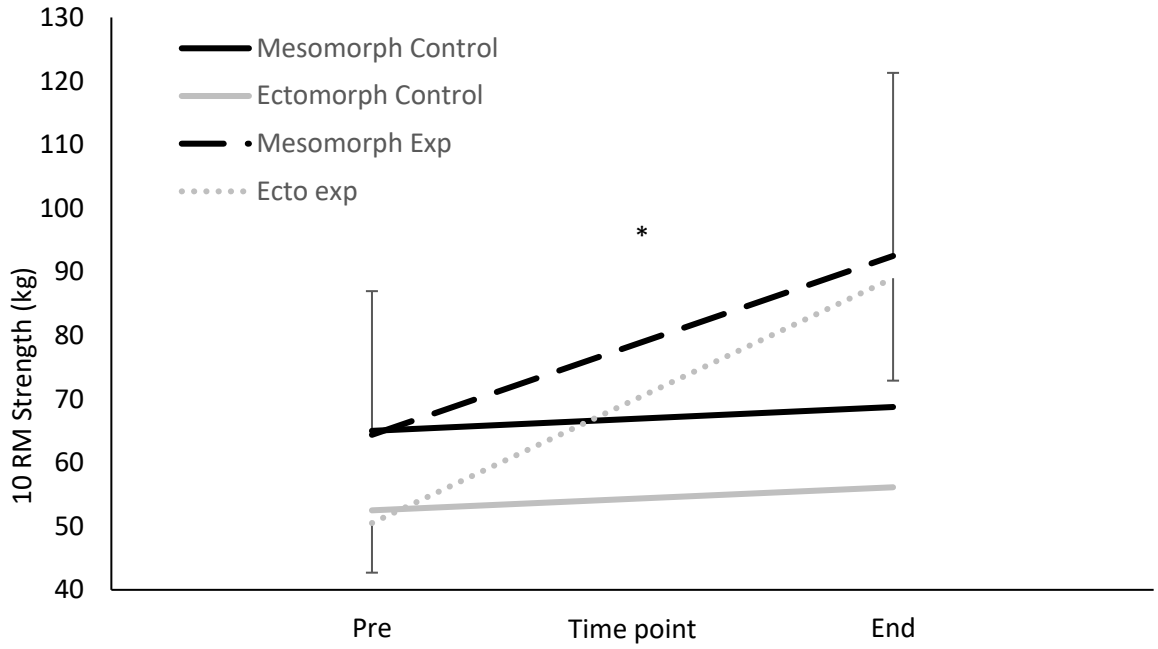


Figure 6.2: Mean absolute (kg) change in 10 RM back squat performance in the two groups for the control and experimental (exp) conditions

** Significant difference (p <0.05) between somatotype groups for change in 10 RM in training condition over time.*

For the bicep curl, there was a significant main time effect (F[1, 14] = 78.49, $p < 0.01$, $\eta_p^2 = 0.85$ [CI 0.66-0.90]), reflecting an overall increase in 10 RM performance over time (Table 6.3). There was also a significant condition main effect (F[1, 14] = 15.51, $p < 0.01$, $\eta_p^2 = 0.53$ [CI 0.17-0.69]). This is indicative of a higher overall 10 RM bicep curl mean in the training condition compared to the control. There was no significant somatotype main effect ($p > 0.05$, $\eta_p^2 = 0.17$ [CI 0.00-0.42]). There was a significant time by condition interaction effect (F[1, 14] = 43.48, $p < 0.01$, $\eta_p^2 = 0.76$ [CI 0.49-0.84]) reflecting a greater increase in bicep curl 10 RM over time in the training condition versus the control (Table 6.3). There were no other significant interaction effects for bicep curl ($p > 0.05$), with the mesomorph group (26.1%) and ectomorph group (50.0%) demonstrating increases in 10 RM performance over the training programme that were not significantly different (Table 6.3).

Table 6.3: Mean (± SD) absolute (kg) change in strength performance in the mesomorph and ectomorph groups.

Exercise	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
	Training	Control	Training	Control
Back squat	28.1 ± 8.8	3.8 ± 9.5	35.4 ± 16.2	3.6 ± 4.7
Close grip bench press	14.3 ± 7.5	1.3 ± 4.5	8.5 ± 5.5	0.3 ± 3.0
Bicep curl	3.1 ± 1.8	0.3 ± 0.9	4.7 ± 1.6	0.9 ± 1.3

6.4.2 Hypertrophy

For the BB MT, there was a significant time main effect (F[1, 14] = 38.14, $p < 0.01$, $\eta_p^2 = 0.73$ [CI 0.45-0.82]) reflecting an overall increase in BB MT over time. There was also a significant condition main effect (F[1, 14] = 52.08, $p < 0.01$, $\eta_p^2 = 0.79$ [CI 0.54-0.86]). This is indicative of a higher overall BB MT mean in the training condition compared to the control condition. There was no significant somatotype main effect ($p > 0.05$). There was a significant time by condition interaction effect (F[1,14] = 47.34, $p < 0.01$, $\eta_p^2 = 0.77$ [CI 0.52-0.85]) reflecting a greater increase in BB MT over time in the training condition versus the control (Figure 6.3). There was a significant time by somatotype interaction effect (F[1, 14] = 14.33, $p < 0.01$, $\eta_p^2 = 0.51$ [CI 0.16-0.67]), indicating a significant difference in the way the BB MT changes over time between the somatotype groups. There were no other significant interaction effects ($p >0.05$), with the mesomorph group (8.4%) and the ectomorph group (5.1%) experiencing similar increases in BB MT in the training condition.

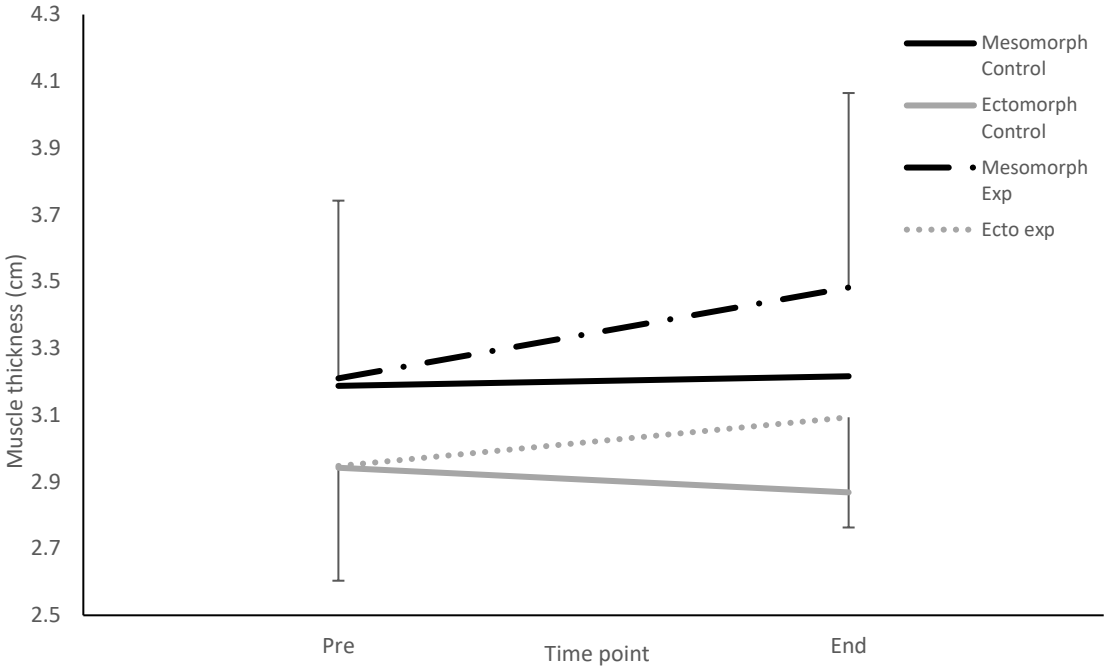


Figure 6.3: Mean absolute change (cm) in BB MT between somatotype groups and conditions

For the TB MT, there was a significant time main effect ($F[1,14] = 29.70$, $p < 0.01$, $\eta_p^2 = 0.68$ [CI 0.37-0.79]), reflecting an overall increase in TB MT over time. There was also a significant condition main effect ($F[1, 14] = 14.21$, $p < 0.01$, $\eta_p^2 = 0.50$ [CI 0.15-0.67]). This is indicative of a higher overall TB MT mean in the training condition compared to the control condition. There was no significant somatotype main effect ($p > 0.05$). There was a significant time by condition interaction effect ($F[1, 14]= 23.60$, $p < 0.01$, $\eta_p^2 = 0.63$ [CI 0.29-0.75]) reflecting a greater increase in TB MT over time in the training condition versus the control (Figure 6.4). There was a significant time by somatotype interaction effect ($F[1, 14] = 15.25$, $p < 0.01$, $\eta_p^2 = 0.52$ [CI 0.17-0.68]), indicating a significant difference in the way the TB MT changes over time between the somatotype groups. There was also a significant condition by somatotype interaction effect ($F[1, 14] = 7.56$, $p < 0.05$, $\eta_p^2 = 0.36$ [CI 0.04-0.56]). This was indicative of a higher mean value in the training condition for the mesomorph group compared to the control and ectomorph values. Finally, there was a significant time by condition by somatotype interaction effect ($F[1, 14] = 11.72$, $p < 0.01$, $\eta_p^2 = 0.46$ [CI 0.11-0.64]) with the mesomorph group (14.9%) experiencing a larger increase in relative MT at the TB over the 8 week training period compared to the ectomorph group (2.6%) (Figure 6.4).

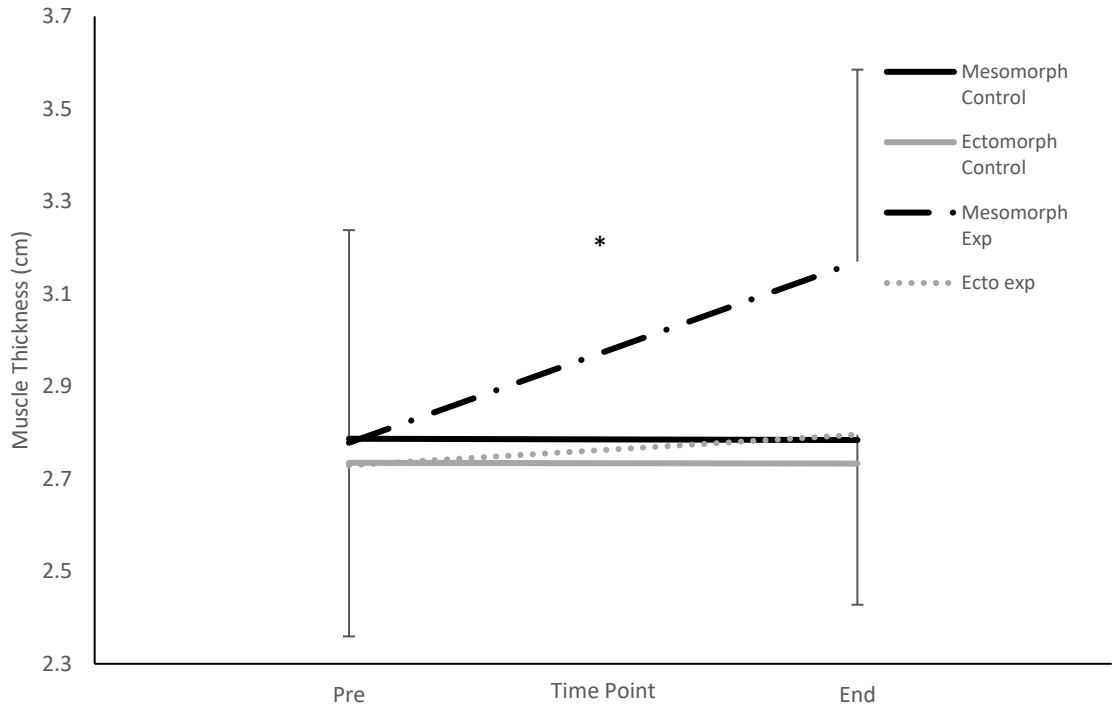


Figure 6.4: Mean absolute change (cm) in TB MT between somatotype groups and conditions

** = significant somatotype by condition by time interaction effect, p < 0.01*

For the BF, there was a significant time main effect (F[1,14] = 39.32, $p < 0.01$, $\eta_p^2 = 0.74$ [CI 0.46-0.83]), reflecting an overall increase in RF MT over time. There was also a significant condition main effect (F[1, 14] = 7.03, $p < 0.05$, $\eta_p^2 = 0.33$ [CI 0.03-0.55]). This was indicative of a higher overall RF MT mean in the training condition compared to the control condition. There was no significant somatotype main effect ($p > 0.05$). There was a significant time by condition interaction effect (F[1, 14]= 17.14, $p < 0.01$, $\eta_p^2 = 0.55$ [CI 0.20-0.70]) reflecting a greater increase in RF MT over time in the training condition versus the control (Figure 6.5). There was a significant time by somatotype interaction effect (F[1, 14] = 6.40, $p < 0.05$, $\eta_p^2 = 0.31$ [CI 0.03-0.54]), indicating a significant difference in the way the RF MT changes over time between the somatotype groups. There was also a significant condition by somatotype interaction effect (F[1, 14] = 8.05, $p < 0.05$, $\eta_p^2 = 0.37$ [CI 0.05-0.58]). This was indicative of a higher mean value in the training condition for the mesomorph group compared to the control and ectomorph values. Finally, there was a significant time by condition by somatotype interaction effect (F[1, 14] = 9.60, $p < 0.01$, $\eta_p^2 = 0.41$ [CI 0.08-0.61]) with the mesomorph group (11.2%) experiencing a larger increase in relative MT at the BF over the 8 week training period compared to the ectomorph group (3.4%) (Figure 6.5).

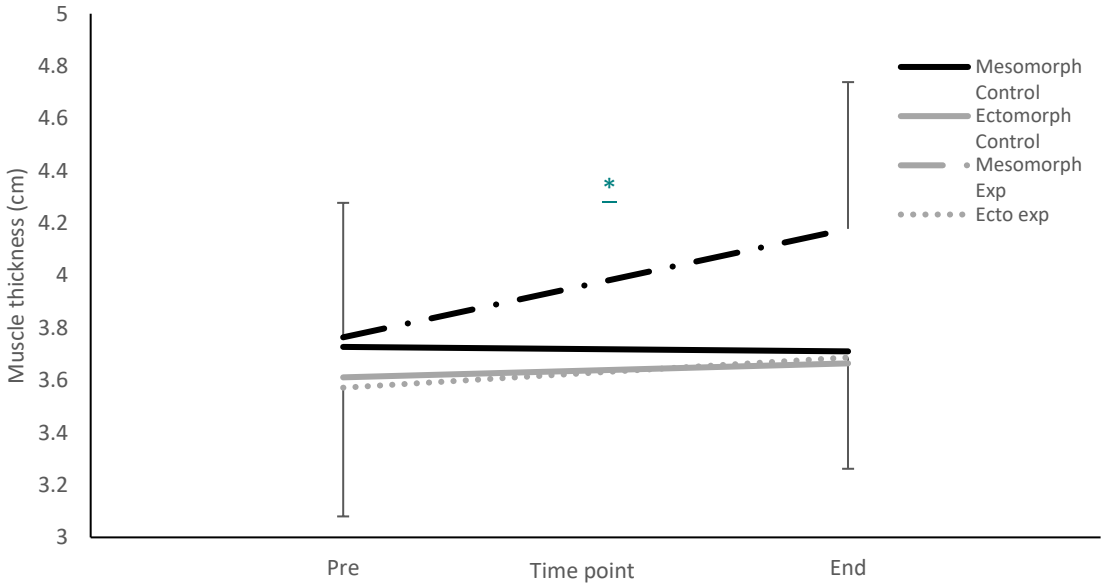


Figure 6.5: Mean absolute change (cm) in BF MT between somatotype groups and conditions

** = significant somatotype by condition by time interaction effect, p < 0.01*

For the RF, there was a significant time main effect (F[1,14] = 29.26, $p < 0.01$, $\eta_p^2 = 0.68$ [CI 0.36-0.79]), reflecting an overall increase in RF MT over time. There was no significant condition main effect ($p > 0.05$, $\eta_p^2 = 0.19$ [CI 0.00-0.43]), nor a significant somatotype main effect ($p > 0.05$). There was a significant time by condition interaction effect (F[1, 14]= 5.66, $p < 0.05$, $\eta_p^2 = 0.29$ [CI 0.01-0.52]) reflecting a greater increase in RF MT over time in the training condition versus the control (Figure 6.6). There was a significant time by somatotype interaction effect (F[1, 14] = 5.34, $p < 0.05$, $\eta_p^2 = 0.28$ [CI 0.01-0.51]), indicating a significant difference in the way the RF MT changes over time between the somatotype groups. There were no further significant interaction effects ($p > 0.05$).

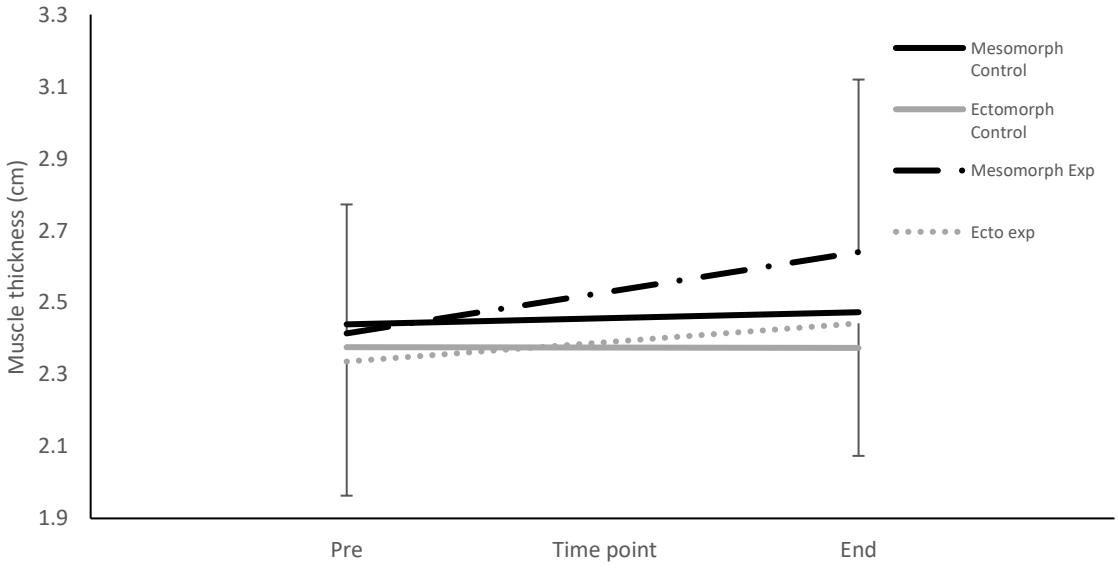


Figure 6.6: Mean absolute change (cm) in RF MT between somatotype groups and conditions

For the CRAG, there was a significant time main effect (F[1,14] = 81.25, $p < 0.01$, $\eta_p^2 = 0.85$ [CI 0.67-0.90]), reflecting an overall increase in CRAG over time (Table 6.4). There was also a significant condition main effect (F[1, 14] = 6.14, $p < 0.05$, $\eta_p^2 = 0.31$ [CI 0.02-0.53]). This was indicative of a higher overall CRAG mean in the training condition compared to the control condition. There was no significant somatotype main effect ($p > 0.05$, $\eta_p^2 = 0.22$ [CI 0.00-0.46]). There was a significant time by condition interaction effect (F[1, 14]= 23.90, $p < 0.01$, $\eta_p^2 = 0.63$ [CI 0.30-0.76]) reflecting a greater increase in CRAG over time in the training condition versus the control (Table 6.4). There was a significant time by somatotype interaction effect (F[1, 14] = 21.03, $p < 0.01$, $\eta_p^2 = 0.60$ [CI 0.26-0.74]), indicating a significant difference in the way the CRAG changes over time between the somatotype groups. There was also a significant condition by somatotype interaction effect (F[1, 14] = 37.46, $p < 0.01$, $\eta_p^2 = 0.73$ [CI 0.44-0.82]). This was indicative of a higher mean value in the training condition for the mesomorph group compared to the control and ectomorph values. Finally, there was a significant time by condition by somatotype interaction effect (F[1, 14] = 59.15, $p < 0.01$, $\eta_p^2 = 0.81$ [CI 0.58-0.87]) likely reflecting the negative direction of change in the ectomorph group in the control condition. During the training period the mesomorph (3.2%) and ectomorph (3.4%) group experienced a similar increase in CRAG (Table 6.4).

For the CAGFT, there was a significant time main effect (F[1,14] = 17.66, $p < 0.01$, $\eta_p^2 = 0.56$ [CI 0.21-0.71]), reflecting an overall increase in CAGFT over time (Table 6.4). There was also a significant condition main effect (F[1, 14] = 10.78, $p < 0.01$, $\eta_p^2 = 0.44$ [CI 0.10-0.63]). This was indicative of a higher overall CAGFT mean in the training condition compared to the control condition. There was a significant somatotype main effect (F[1, 14] = 6.83, $p < 0.05$, $\eta_p^2 = 0.33$ [CI 0.03-0.55]), representing a higher overall mean CAGFT in the mesomorph group compared to the ectomorph. There was a significant time by condition interaction effect (F[1, 14]= 17.96, $p < 0.01$, $\eta_p^2 = 0.56$ [CI 0.21-0.71]) reflecting a greater increase in CAGFT over time in the training condition versus the control (Table 6.4). There were no further significant interaction effects ($p > 0.05$). The mesomorph group (3.0%) experienced a similar increase in CAGFT over the 8-week training period compared to the ectomorph group (3.1%) (Table 6.4).

Table 6.4: Absolute (mean ± SD) change (cm) in arm girth measurements between mesomorphs and ectomorphs.

Measurement	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
	Training	Control	Training	Control
Corrected relaxed arm girth (cm)	1.0 ± 0.7	0.4 ± 1.0	0.9 ± 0.8	-0.5 ± 0.6
Corrected arm girth flexed and tensed (cm)	1.0 ± 0.3	0.1 ± 0.9	0.9 ± 0.8	-0.2 ± 0.4

Significant positive correlations were observed between mesomorphy rating and change (0-8 weeks training) in BB MT (r = 0.50, $p < 0.025$, Figure 6.7), TB MT (r = 0.69, $p < 0.01$, Figure 6.8), and BF MT (r = 0.75, $p < 0.01$, Figure 6.9). Significant negative correlations were observed between ectomorphy rating and change in BB MT (r = -0.65, $p < 0.01$, Figure 6.7), TB MT (r = -0.76, $p < 0.01$, Figure 6.8), and BF MT (r = -0.72, $p < 0.01$, Figure 6.9). There were no significant correlations between somatotype ratings and RF MT or arm girth measurements.

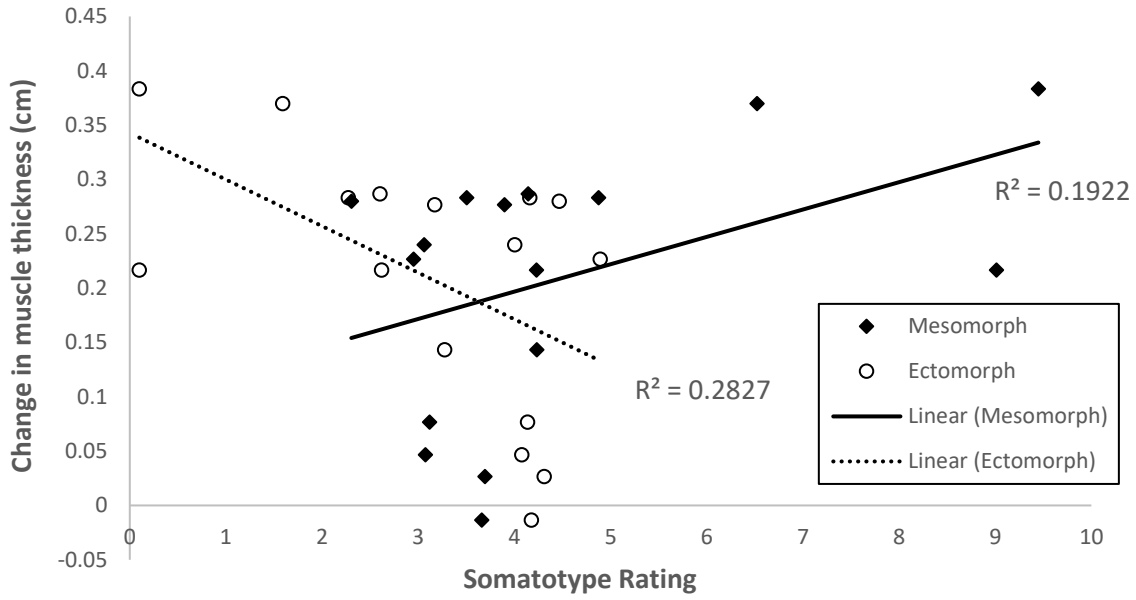


Figure 6.7: Relationship between change in BB MT and somatotype rating.

*Significant correlation: # p < 0.01; * p < 0.025.*

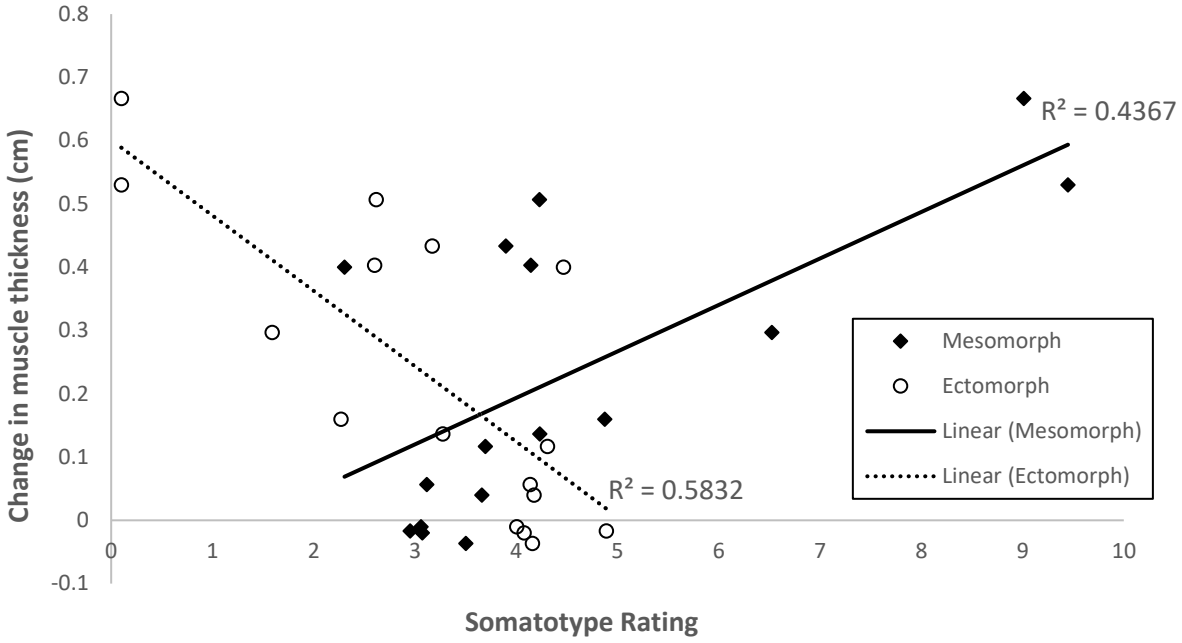


Figure 6.8: Relationship between change in TB MT and somatotype rating.

Significant correlation: # p < 0.01.

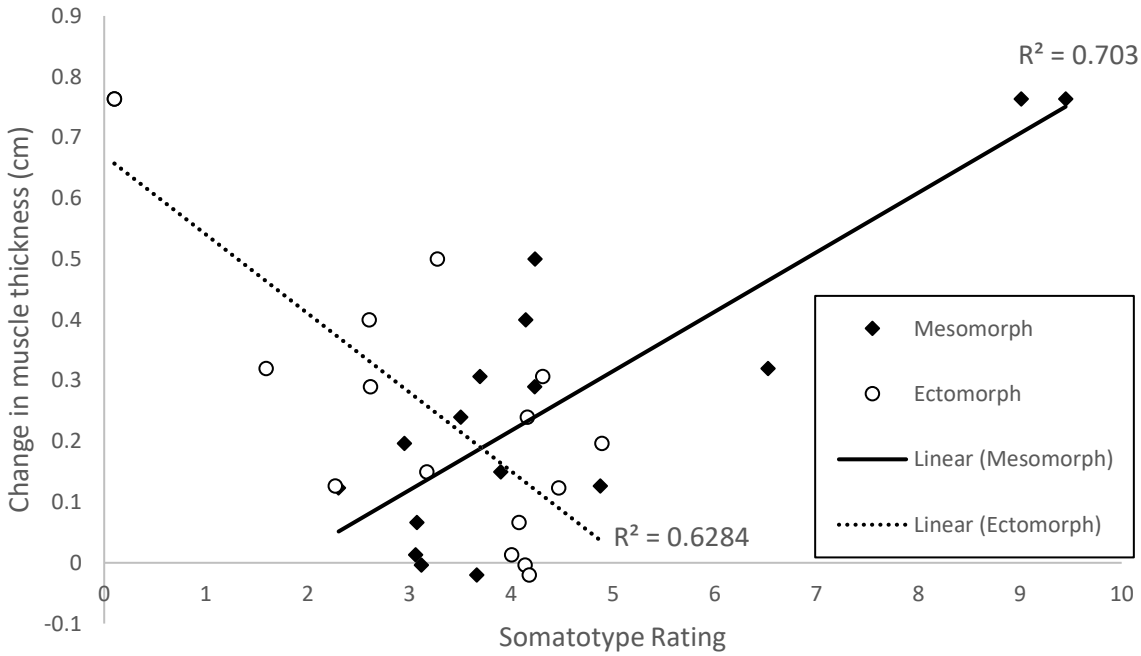


Figure 6.9: Relationship between change in BF MT and somatotype rating.

Significant correlation: # p < 0.01.

6.4.3 EMG

6.4.3.1 Peak Amplitude

For the back squat there was no significant time or condition main effect for RF PAm during the concentric phase ($p > 0.05$). There was a significant somatotype main effect (F[1, 14] = 10.49, $p < 0.01$, $\eta_p^2 = 0.43$ [CI 0.09-0.62]) representing a significantly higher PAm in the RF of the ectomorph group (Table 6.5). There were no significant interaction effects for RF PAm during the concentric phase ($p > 0.05$), although the time by somatotype interaction effect demonstrated a large effect size ($\eta_p^2 = 0.19$ [CI 0.00-0.43]). There was no significant time or condition main effect for RF PAm during the eccentric phase ($p > 0.05$). There was a significant somatotype main effect (F[1, 14] = 5.07, $p < 0.05$, $\eta_p^2 = 0.27$ [CI 0.01-0.50]) representing a significantly higher PAm in the RF of the ectomorph group (Table 6.5). There was a significant condition by time interaction effect (F[1,14] = 7.58, $p < 0.05$, $\eta_p^2 = 0.35$ [CI 0.04-0.57]). This reflected an increase from baseline to end in PAm in the RF during the eccentric phase in the training condition, but a decrease across the control condition (Table 6.5). There were no other significant interaction effects for RF PAm during the eccentric phase of the back squat ($p > 0.05$). There was no significant time or condition main effect for BF PAm during the concentric phase of the back squat ($p > 0.05$). There was a significant somatotype main effect (F[1, 14] = 4.80, $p < 0.05$, $\eta_p^2 = 0.26$ [CI 0.00-0.49]) representing a significantly higher PAm in the BF of the mesomorph group (Table 6.5). There were no significant interaction effects for BF PAm during the concentric phase ($p > 0.05$), although the condition by time by somatotype interaction effect demonstrated a large effect size ($\eta_p^2 = 0.14$ [CI 0.00-0.39]). There were no significant main or interaction effects for BF PAm during the eccentric phase of the back squat ($p > 0.05$), although the condition by time by somatotype interaction effect demonstrated a large effect size ($\eta_p^2 = 0.24$ [CI 0.00-0.48]).

For the close grip bench press, there were no significant main or interaction effects for the BB PAm during the concentric phase ($p > 0.05$). During the eccentric phase there were no significant main effects for the BB PAm ($p > 0.05$), although the time main effect demonstrated a large effect size ($\eta_p^2 = 0.16$ [CI 0.00-0.41]). There were no significant interaction effects for the BB PAm during the eccentric phase ($p > 0.05$), although the condition by somatotype by time interaction effect demonstrated a large effect size ($\eta_p^2 = 0.23$ [CI 0.00-0.47]). There were no significant main effects for the TB PAm in the concentric phase of the close grip bench press ($p > 0.05$). There were no significant interaction effects for the TB PAm during the concentric phase ($p > 0.05$), although the condition by somatotype interaction effect demonstrated a large effect size ($\eta_p^2 = 0.21$ [CI 0.00-0.45]). There were no significant main effects for the TB PAm in the eccentric phase of the close grip

bench press ($p > 0.05$). There was a significant condition by time interaction effect (F[1, 14] = 10.10, $p < 0.01$, $\eta_p^2 = 0.42$ [CI 0.08-0.61]), with the control condition demonstrating a decrease in PAm in the TB over time, whilst the training condition saw an increase (Table 6.5). There were no other significant interaction effects for the TB PAm during the eccentric phase, although the condition by somatotype ($\eta_p^2 = 0.15$ [CI 0.00-0.40]) and time by somatotype ($\eta_p^2 = 0.15$ [CI 0.00-0.40]) demonstrated large effect sizes.

For the bicep curl, there were no significant main or interaction effects for the BB PAm during the concentric phase ($p > 0.05$). There was a significant main time effect for the BB PAm during the eccentric phase of the bicep curl (F[1, 14] = 12.20, $p < 0.01$, $\eta_p^2 = 0.47$ [CI 0.12-0.65]), with an increase in PAm over time (Table 6.5). There was no significant condition main effect ($p > 0.05$). There was a significant somatotype main effect for the BB PAm during the eccentric phase (F[1, 14] = 6.60, $p < 0.05$, $\eta_p^2 = 0.32$ [CI 0.03-0.54]), representing a higher overall PAm in the ectomorph group compared to the mesomorphs (Table 6.5). There was a significant time by somatotype interaction effect (F[1, 14] = 9.44, $p < 0.01$, $\eta_p^2 = 0.40$ [CI 0.07-0.60]), with the ectomorph group experiencing a larger increase in PAm over time compared to the mesomorph group. There were no other significant interaction effects for the BB PAm during the eccentric phase of the bicep curl. There were no significant main effects for the TB PAm during the concentric phase of the bicep curl, although the somatotype main effect demonstrated a large effect size ($\eta_p^2 = 0.18$ [CI 0.00-0.43]). There was a significant time by condition by somatotype interaction effect for TB PAm during the concentric phase (F[1, 14] = 5.15, $p < 0.05$, $\eta_p^2 = 0.27$ [CI 0.01-0.50]). This was indicative of the mesomorph group demonstrating an increase in PAm over the training condition, whilst the ectomorph group experienced a decrease over the same condition (Table 6.5). There were no other significant interaction effects ($p > 0.05$), although the condition by somatotype ($\eta_p^2 = 0.17$ [CI 0.00-0.41]) and condition by time ($\eta_p^2 = 0.18$ [CI 0.00-0.43]) interaction effect demonstrated large effect sizes. There were no significant main effects for the TB during the eccentric phase of the bicep curl ($p > 0.05$), although the time ($\eta_p^2 = 0.15$ [CI 0.00-0.30]) and somatotype ($\eta_p^2 = 0.21$ [CI 0.00-0.45]) main effect demonstrated a large effect size. There were no significant interaction effects for the TB during the eccentric phase of the bicep curl ($p > 0.05$), although there were large effect sizes for condition by somatotype ($\eta_p^2 = 0.21$ [CI 0.00-0.45]) and condition by time by somatotype ($\eta_p^2 = 0.22$ [CI 0.00-0.46]).

Table 6.5: Mean (± SD) change in peak EMG amplitudes (mV) across the different exercises and muscles during control and training periods

Exercise	Muscle	Contraction	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
			Training	Control	Training	Control
Back squat	Rectus Femoris	Concentric	-0.05 ± 0.56	-0.27 ± 1.26	0.66 ± 0.98	0.41 ± 1.27
		Eccentric	0.41 ± 0.38	-0.62 ± 1.23	0.74 ± 0.99	0.11 ± 0.82
	Biceps Femoris	Concentric	0.27 ± 1.70	-0.34 ± 1.64	-0.29 ± 0.80	0.43 ± 0.84
		Eccentric	0.26 ± 1.04	-0.94 ± 2.84	-0.03 ± 0.33	1.01 ± 1.53
Close grip bench press	Bicep brachii	Concentric	-0.20 ± 0.77	-0.12 ± 2.62	0.20 ± 1.38	0.22 ± 1.13
		Eccentric	0.04 ± 0.98	0.69 ± 1.05	0.57 ± 1.22	-0.24 ± 0.41
	Triceps brachii	Concentric	0.95 ± 1.06	-0.86 ± 1.78	0.11 ± 3.16	-0.12 ± 0.97
		Eccentric	0.93 ± 1.14	-1.11± 1.86	1.10 ± 0.96	-0.17 ± 0.76
Bicep Curl	Bicep Brachii	Concentric	-1.31 ± 2.50	-0.61 ± 4.61	0.48 ± 4.40	-1.84 ± 4.65
		Eccentric	-0.67 ± 2.28	0.80 ± 2.21	1.01 ± 3.50	1.11 ± 2.99
	Triceps Brachii	Concentric	0.60 ± 0.89	-1.49 ± 2.15	-0.16 ± 1.02	0.09 ± 0.29
		Eccentric	0.34 ± 0.62	-1.52 ± 2.52	-0.35 ± 1.45	-0.05 ± 0.16

Significant positive correlations were observed between change in absolute bicep curl strength and change in BB concentric peak amplitude (r = 0.56, $p < 0.025$), and change in BB eccentric peak amplitude (r = 0.63, $p < 0.01$) (Figure 6.10). There was also a significant positive correlation between change in absolute back squat strength and change in RF concentric peak amplitude (r = 0.61, $p < 0.025$, Figure 6.11).

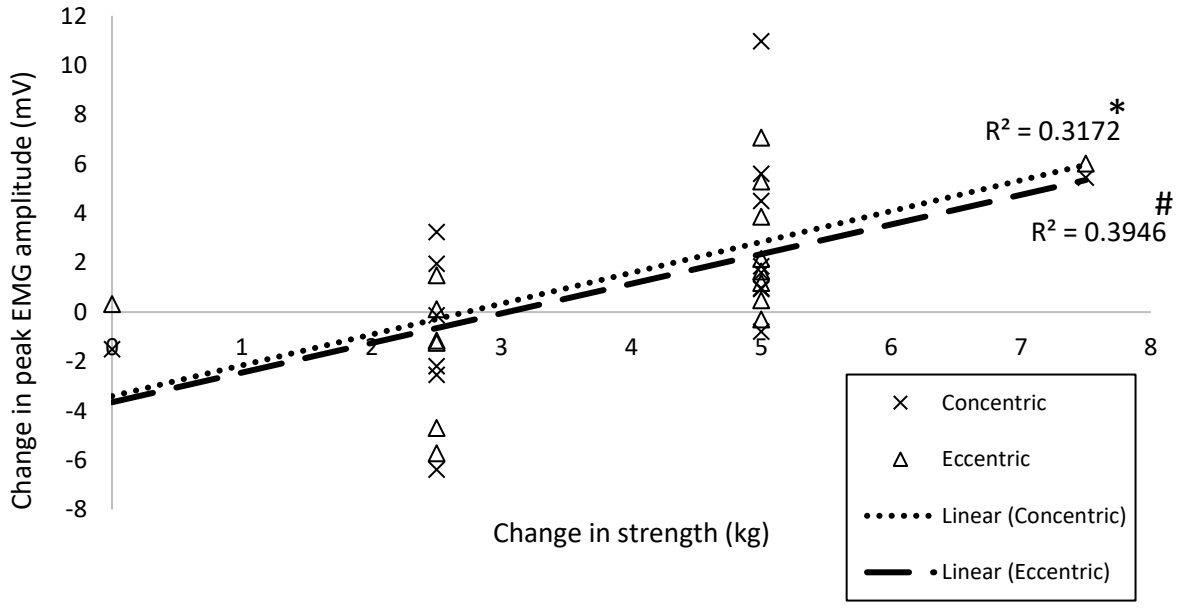


Figure 6.10: Relationship between change in BC strength (kg) and change in BB peak EMG amplitude (mV) during the BC.

*Significant correlation: # p < 0.01; * p < 0.025.*

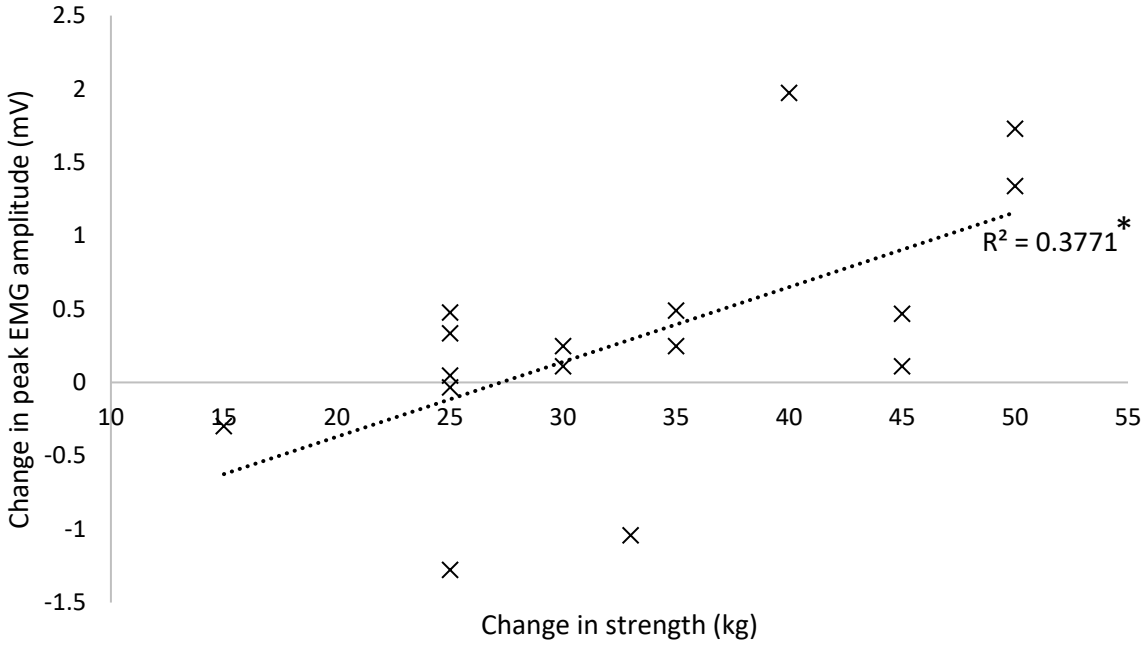


Figure 6.11: Relationship between change in BS strength (kg) and change in RF peak EMG amplitude (mV) during the BS.

*Significant correlation: * p < 0.025.*

6.4.3.2 Time to peak

For the back squat there were no significant main effects for RF TTP during the concentric phase (p > 0.05). There were also no significant interaction effects for RF TTP during the concentric phase (p > 0.05). There was no significant condition or somatotype main effect for RF TTP during the eccentric phase (p > 0.05). There was a significant time main effect (F[1, 14] = 5.85, p < 0.05, η_p^2 = 0.30 [CI 0.02-0.52]) representing an overall increase in TTP over the 8-week period. There were no significant interaction effects for RF TTP during the eccentric phase of the back squat (p > 0.05). There were no significant main or interaction effects for BF TTP during the concentric phase of the back squat (p > 0.05). For the BF TTP during the eccentric phase of the back squat there was a significant condition main effect (F[1, 14] = 6.75, p < 0.05, η_p^2 = 0.33 [CI 0.03-0.55]). The TTP was higher overall in the training condition versus the control (Table 6.6). There was also a significant time main effect (F[1, 14] = 15.58, p < 0.01, η_p^2 = 0.53 [CI 0.18-0.69]), representing an increase in TTP over the 8-week period. There was no significant somatotype main effect (p > 0.05). There were no significant interaction effects, although the time by somatotype interaction effect showed a large effect size (η_p^2 = 0.15 [CI 0.00-0.40]).

For the close grip bench press there were no significant main effects for BB TTP during the concentric phase ($p > 0.05$). There were also no significant interaction effects for BB TTP during the concentric phase ($p > 0.05$), although the time by condition by somatotype interaction demonstrated a large effect size ($\eta_p^2 = 0.23$ [CI 0.00-0.47]). There were no significant main or interaction effects for BB TTP during the eccentric phase of the close grip bench press ($p > 0.05$). For the TB during the concentric phase of the close grip bench press there was no significant condition or somatotype main effect ($p > 0.05$). There was a time main effect ($F[1, 14] = 5.50$, $p < 0.05$, $\eta_p^2 = 0.28$ [CI 0.01-0.51]). This represented an increase in TTP in the TB over the 8-week period. There was also a significant time by somatotype interaction effect ($F[1, 14] = 4.89$, $p < 0.05$, $\eta_p^2 = 0.26$ [CI 0.00-0.49]), reflective of a much larger increase in the TTP over 8-weeks in the mesomorph group compared to the ectomorph group (Table 6.6). There were no further interaction effects ($p > 0.05$). For the TB during the eccentric phase of the close grip bench press there was no significant time or condition main effect ($p > 0.05$). There was a significant somatotype main effect ($F[1, 14] = 5.37$, $p < 0.05$, $\eta_p^2 = 0.28$ [CI 0.01-0.51]), representing a higher overall TTP in the ectomorph group. There was a condition by time interaction effect ($F[1, 14] = 4.98$, $p < 0.05$, $\eta_p^2 = 0.26$ [CI 0.01-0.50]). This was indicative of an increase in TTP during the control, and a decrease in the training condition. There were no other significant interaction effects ($p > 0.05$).

For the bicep curl there were no significant main or interaction effects for the BB TTP during the concentric phase ($p > 0.05$). There were also no significant main or interaction effects for the BB TTP during the eccentric phase ($p > 0.05$), although the time by condition by somatotype interaction demonstrated a large effect size ($\eta_p^2 = 0.14$ [CI 0.00-0.39]). There was a significant condition main effect for the TB TTP during the concentric phase ($F[1, 14] = 5.32$, $p < 0.05$, $\eta_p^2 = 0.28$ [CI 0.01-0.51]), with the training condition having a higher overall TTP (Table 6.6). There was also a significant time main effect for the TB TTP during the concentric phase ($F[1, 14] = 13.54$, $p < 0.01$, $\eta_p^2 = 0.49$ [CI 0.14-0.66]), representing an increase in the TTP over the 8-week period. There was no significant somatotype main effect ($p > 0.05$). There were also no significant interaction effects in the TB during the concentric phase ($p > 0.05$), although the time by somatotype interaction demonstrated a large effect size ($\eta_p^2 = 0.17$ [CI 0.00-0.42]). There were no significant main effects in the TB TTP during the eccentric phase of the bicep curl ($p > 0.05$), although the somatotype main effect demonstrated a large effect size ($\eta_p^2 = 0.16$ [CI 0.00-0.41]). There were also no significant interaction effects ($p > 0.05$).

Table 6.6: Mean change (± SD) in time to peak (TTP) amplitude (s) across the different exercises and muscles during control and training periods

Exercise	Muscle	Contraction	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
			Training	Control	Training	Control
Back squat	Rectus Femoris	Concentric	-0.15 ± 1.38	0.68 ± 1.13	-0.37 ± 2.34	0.19 ± 1.65
		Eccentric	1.26 ± 2.76	0.31 ± 3.82	2.13 ± 2.10	-0.40 ± 2.03
	Biceps Femoris	Concentric	0.12 ± 3.34	0.00 ± 2.01	-0.80 ± 2.37	0.62 ± 2.60
		Eccentric	1.41 ± 1.24	1.47 ± 1.47	-0.05 ± 2.36	1.29 ± 1.55
Bench Press	Bicep brachii	Concentric	-0.44 ± 2.88	2.00 ± 2.57	0.98 ± 3.23	-0.17 ± 2.18
		Eccentric	-0.36 ± 3.56	-0.33 ± 2.87	-1.77 ± 2.86	1.22 ± 2.04
	Triceps brachii	Concentric	0.73 ± 1.91	1.44 ± 1.42	-0.38 ± 1.64	0.45 ± 1.30
		Eccentric	-0.79 ± 1.49	1.28 ± 1.89	-1.97 ± 3.30	1.21 ± 4.30
Bicep Curl	Bicep Brachii	Concentric	-0.27 ± 2.23	0.37 ± 3.53	-1.31 ± 3.14	-0.72 ± 5.46
		Eccentric	1.32 ± 2.22	-0.87 ± 1.84	-0.35 ± 2.65	0.62 ± 2.43
	Triceps Brachii	Concentric	1.66 ± 1.68	0.53 ± 1.29	0.54 ± 2.38	0.27 ± 1.87
		Eccentric	-1.19 ± 3.91	-0.27 ± 4.37	-0.75 ± 2.71	-0.09 ± 3.86

6.4.4 NIRS

6.4.4.1 Lower body

For the RF in the back squat there were no significant main effects for ΔtHb ($p > 0.05$), although the time main effect demonstrated a large effect size ($\eta_p^2 = 0.18$ [CI 0.00-0.42]). There was a significant condition by time by somatotype interaction effect for RF ΔtHb during the back squat ($F[1, 14] = 10.75$, $p < 0.01$, $\eta_p^2 = 0.43$ [CI 0.10-0.62]). This represented an increase in ΔtHb during the training condition in the mesomorph group and a decrease in the ectomorph group (Table 6.7). There were no other significant interaction effects ($p > 0.05$). For the BF in the back squat there were no significant main effects for ΔtHb ($p > 0.05$), although the somatotype main effect demonstrated a large effect size ($\eta_p^2 = 0.24$ [CI 0.00-0.48]). There were no significant interaction effects for ΔtHb in the BF during the back squat ($p > 0.05$).

Table 6.7: Mean (± SD) ΔtHb for the back squat during control and training periods (μM)

Exercise	Muscle	Time point	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
			Training	Control	Training	Control
Back Squat	Rectus Femoris	0 weeks	1.51 (± 2.48)	13.10 (± 36.90)	7.83 (± 15.48)	-1.32 (± 8.82)
		8 weeks	6.36 (± 11.93)	1.65 (± 3.27)	-6.19 (± 5.78)	-12.26 (± 20.20)
	Biceps Femoris	0 weeks	0.00 (± 5.84)	-2.75 (± 7.33)	-1.51 (± 12.05)	-3.92 (± 5.89)
		8 weeks	0.31 (± 11.90)	5.19 (± 8.55)	-2.78 (± 4.62)	-6.00 (± 6.61)

For the RF in the back squat there were no significant main effects for ΔO2Hb ($p > 0.05$), although the somatotype main effect demonstrated a large effect size ($\eta_p^2 = 0.21$ [CI 0.00-0.45]). There were no significant interaction effects for RF ΔO2Hb during the back squat ($p > 0.05$). For the BF in the

back squat there was a significant main somatotype effect for ΔO2Hb (F[1, 14] = 6.50, $p < 0.05$, η_p^2 = 0.32 [CI 0.03-0.54]). The mesomorph group showed a positive ΔO2Hb, whilst the ectomorph group showed a negative ΔO2Hb (Table 6.8). There were no significant time or condition main effects ($p >$ 0.05). There were no significant interaction effects for ΔO2Hb in the BF during the back squat ($p >$ 0.05), although the time by somatotype interaction demonstrated a large effect size (η_p^2 = 0.15; [CI 0.00-0.39]).

Table 6.8: Mean (± SD) ΔO2Hb for the back squat during control and training periods (μM)

Exercise	Muscle	Time point	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
			Training	Control	Training	Control
Back Squat	Rectus Femoris	0 weeks	-2.58 (± 2.83)	5.65 (± 29.64)	0.89 (± 9.91)	-6.23 (± 6.90)
		8 weeks	3.34 (± 8.30)	-1.84 (± 4.49)	-3.92 (± 4.34)	-9.90 (± 6.08)
	Biceps Femoris	0 weeks	0.17 (± 3.15)	-2.37 (± 3.48)	-1.37 (± 10.63)	-2.72 (± 3.66)
		8 weeks	0.84 (± 8.73)	1.97 (± 2.62)	-4.18 (± 7.04)	-5.88 (± 7.49)

For the RF in the back squat there were no significant main effects for ΔHHb ($p >$ 0.05), although the time main effect demonstrated a large effect size (η_p^2 = 0.16 [CI 0.00-0.40]). There were no significant interaction effects for RF ΔHHb during the back squat ($p >$ 0.05), although the condition by time by somatotype interaction demonstrated a large effect size (η_p^2 = 0.14 [CI 0.00-0.39]). For the BF in the back squat there were no significant main effects for ΔHHb ($p >$ 0.05), although the somatotype main effect did demonstrate a large effect size (η_p^2 = 0.21 [CI 0.00-0.45]). There were also no significant interaction effects for ΔHHb in the BF during the back squat ($p >$ 0.05), although the time by somatotype interaction demonstrated a large effect size (η_p^2 = 0.15 [CI 0.00-0.39]) (Table 6.9).

Table 6.9: Mean (± SD) ΔHHb for the back squat during control and training periods (μM)

Exercise	Muscle	Time point	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
			Training	Control	Training	Control
Back Squat	Rectus Femoris	0 weeks	4.09 (± 2.06)	11.27 (± 18.30)	6.93 (± 7.04)	4.64 (± 7.55)
		8 weeks	3.30 (± 4.09)	3.49 (± 1.95)	1.44 (± 1.78)	4.45 (± 14.00)
	Biceps Femoris	0 weeks	-0.17 (± 2.78)	-0.38 (± 4.32)	0.26 (± 4.87)	-1.39 (± 2.53)
		8 weeks	3.07 (± 5.58)	1.53 (± 3.36)	-0.19 (± 3.48)	-4.26 (± 6.07)

For the RF in the back squat there were no significant main effects for ΔTSI ($p >$ 0.05). There was a significant time by somatotype interaction effect (F[1, 14] = 7.62, $p < 0.05$, η_p^2 = 0.35 [CI 0.04-0.57]). Over the 8-week period the mesomorph group experienced an increase in TSI, whilst the ectomorph

group experienced at decrease (Table 6.10). There were no other significant interaction effects for RF ΔTSI during the back squat ($p > 0.05$). For the BF in the back squat there were no significant main effects for ΔTSI ($p > 0.05$). There were also no significant interaction effects for ΔTSI in the BF during the back squat ($p > 0.05$), although the time by somatotype interaction demonstrated a large effect size ($\eta_p^2 = 0.20$ [CI 0.00-0.44]).

Table 6.10: Mean (± SD) ΔTSI for the back squat during control and training periods (%)

Exercise	Muscle	Time point	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
			Training	Control	Training	Control
Back Squat	Rectus Femoris	0 weeks	-6.09 (± 3.83)	-7.88 (± 3.85)	0.74 (± 19.88)	-6.35 (± 9.16)
		8 weeks	-1.60 (± 5.56)	-2.78 (± 7.60)	-4.78 (± 3.46)	-10.06 (± 6.67)
	Biceps Femoris	0 weeks	0.11 (± 1.61)	-3.90 (± 5.90)	4.68 (± 18.66)	0.45 (± 5.94)
		8 weeks	1.72 (± 14.52)	1.58 (± 1.91)	-2.62 (± 5.72)	-4.45 (± 8.86)

6.4.4.2 Upper body

For the BB in the close grip bench press there were no significant main effects for ΔtHb ($p > 0.05$). There were also no significant interaction effects ($p > 0.05$), although the time by condition by somatotype interaction demonstrated a large effect size ($\eta_p^2 = 0.14$ [CI 0.00-0.39]). For the TB in the close grip bench press there were no significant main effects for ΔtHb ($p > 0.05$), although the somatotype main effect demonstrated a large effect size ($\eta_p^2 = 0.16$ [0.00-0.41]). There was a significant time by somatotype interaction effect ($F[1, 14] = 6.37$, $p < 0.05$, $\eta_p^2 = 0.31$ [CI 0.02-0.54]). This represented a decrease in ΔtHb in the mesomorph group and an increase in the ectomorph group over the 8-week period (Table 6.11). There were no other significant interaction effects for ΔtHb in the TB during the close grip bench press ($p > 0.05$), although the time by condition by somatotype interaction demonstrated a large effect size ($\eta_p^2 = 0.15$ [CI 0.00-0.40]).

For the BB in the bicep curl there were no significant main effects for ΔtHb ($p > 0.05$). There was a significant condition by time interaction effect ($F[1, 14] = 5.51$, $p < 0.05$, $\eta_p^2 = 0.28$ [CI 0.01-0.51]), with a decrease in BB ΔtHb in the control 8-weeks and an increase in BB ΔtHb in the training 8-weeks (Table 6.11). There were no further significant interaction effects ($p > 0.05$). For the TB in the bicep curl there were no significant main effects for ΔtHb ($p > 0.05$). There were also no significant interaction effects for ΔtHb in the TB during the bicep curl ($p > 0.05$).

Table 6.11: Mean (± SD) ΔtHb for the upper body exercises during control and training periods (μM)

Exercise	Muscle	Time point	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
			Training	Control	Training	Control
Close grip bench press	Bicep Brachii	0 weeks	0.55 (± 5.29)	1.31 (± 8.99)	1.88 (± 2.35)	0.23 (± 7.10)
		8 weeks	5.89 (± 5.38)	0.98 (± 5.29)	-0.18 (± 4.87)	1.57 (± 4.61)
	Triceps Brachii	0 weeks	-3.43 (± 7.52)	5.97 (± 14.04)	4.09 (± 4.24)	-0.38 (± 7.62)
		8 weeks	-1.13 (± 4.31)	-2.38 (± 9.96)	4.83 (± 8.29)	4.07 (± 4.17)
Bicep curl	Bicep Brachii	0 weeks	-4.20 (± 8.94)	5.43 (± 6.53)	1.24 (± 9.42)	4.37 (± 10.72)
		8 weeks	11.38 (± 20.55)	-1.71 (± 11.62)	4.04 (± 7.28)	-1.72 (± 3.85)
	Triceps Brachii	0 weeks	0.95 (± 3.81)	0.25 (± 2.25)	0.31 (± 11.39)	2.00 (± 4.13)
		8 weeks	1.90 (± 2.67)	1.45 (± 4.90)	1.14 (± 5.67)	0.89 (± 5.26)

For the BB in the close grip bench press there were no significant main effects for ΔO2Hb ($p > 0.05$), although the somatotype main effect demonstrated a large effect size ($\eta_p^2 = 0.19$ [CI 0.00-0.44]). There was a significant time by condition by somatotype interaction effect for ΔO2Hb in the BB ($F[1, 14] = 4.91$, $p < 0.05$, $\eta_p^2 = 0.26$ [CI 0.00-0.50]). The mesomorph group demonstrated a decrease in ΔO2Hb in the control condtion and an increase in the training condition, whilst the ectomorph group experienced the opposite pattern of results (Table 6.12). There were no other significant interaction effects for ΔO2Hb in the BB for the close grip bench press ($p > 0.05$). For the TB in the close grip bench press there were no significant main effects for ΔO2Hb ($p > 0.05$). There was a significant time by somatotype interaction effect ($F[1, 14] = 4.84$, $p < 0.05$, $\eta_p^2 = 0.26$ [CI 0.00-0.49]). This represented a decrease in ΔO2Hb in the mesomorph group and an increase in the ectomorph group over the 8-week period. There were no other significant interaction effects for ΔO2Hb in the TB during the close grip bench press ($p > 0.05$), although the condition by somatotype interaction demonstrated a large effect size ($\eta_p^2 = 0.15$ [CI 0.00-0.40]).

For the BB in the bicep curl there were no significant main effects for ΔO2Hb ($p > 0.05$). There were also no significant interaction effects ($p > 0.05$). For the TB in the bicep curl there were no significant main effects for ΔO2Hb ($p > 0.05$), although the somatotype main effect demonstrated a large effect size ($\eta_p^2 = 0.24$ [CI 0.00-0.48]). There was a significant condition by time by somatotype interaction effect for ΔO2Hb in the TB during the bicep curl ($F[1, 14] = 6.96$, $p < 0.05$, $\eta_p^2 = 0.33$ [CI 0.03-0.55]). The mesomorph group showed an increase in ΔO2Hb across the training condition, whilst the ectomorph group showed a decrease across the same condition (Table 6.12). There were no further significant interaction effects for ΔO2Hb in the TB during the bicep curl ($p > 0.05$).

Table 6.12: Mean (± SD) ΔO2Hb for the upper body exercises and muscles during control and training periods (μM)

Exercise	Muscle	Time point	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
			Training	Control	Training	Control
Close grip bench press	Bicep Brachii	0 weeks	-0.94 (± 4.77)	4.14 (± 14.12)	-0.32 (± 3.35)	-4.94 (± 9.59)
		8 weeks	2.10 (± 3.86)	-0.42 (± 5.12)	-5.51 (± 8.69)	-0.66 (± 4.72)
	Triceps Brachii	0 weeks	-3.12 (± 5.02)	-0.36 (± 7.67)	-3.95 (± 4.07)	-8.58 (± 8.32)
		8 weeks	-4.10 (± 6.92)	-3.28 (± 6.12)	-1.11 (± 5.87)	-1.90 (± 4.64)
Bicep Curl	Bicep Brachii	0 weeks	-6.63 (± 8.22)	-1.67 (± 5.27)	-5.33 (± 15.35)	-11.26 (± 20.01)
		8 weeks	2.01 (± 15.61)	-3.49 (± 10.88)	-2.97 (± 8.42)	-6.59 (± 8.02)
	Triceps Brachii	0 weeks	-1.03 (± 4.04)	-0.17 (± 2.36)	-2.80 (± 8.00)	-5.59 (± 13.15)
		8 weeks	5.17 (± 16.87)	2.39 (± 7.92)	-8.30 (± 7.32)	-2.17 (± 5.52)

For the BB in the close grip bench press there were no significant main effects for ΔHHb ($p > 0.05$). There were also no significant interaction effects for ΔHHb in the BB for the close grip bench press ($p > 0.05$). For the TB in the close grip bench press there were no significant main effects for ΔHHb ($p > 0.05$). There were also no significant interaction effects for ΔHHb in the TB during the close grip bench press ($p > 0.05$), although the time by condition by somatotype interaction demonstrated a large effect size ($\eta_p^2 = 0.20$ [CI 0.00-0.45]) (Table 6.13).

For the BB in the bicep curl there were no significant main effects for ΔHHb ($p > 0.05$), although the condition ($\eta_p^2 = 0.19$ [CI 0.00-0.44]) and time ($\eta_p^2 = 0.17$ [CI 0.00-0.42]) main effects demonstrated large effect sizes. There were also no significant interaction effects ($p > 0.05$), although large effect sizes were demonstrated for the condition by somatotype ($\eta_p^2 = 0.19$ [CI 0.00-0.44]), time by somatotype ($\eta_p^2 = 0.17$ [CI 0.00-0.42]) and time by condition by somatotype ($\eta_p^2 = 0.16$ [CI 0.00-0.41]) interactions. For the TB in the bicep curl there were no significant main effects for ΔHHb ($p > 0.05$), although the condition ($\eta_p^2 = 0.24$ [CI 0.00-0.48]) and time ($\eta_p^2 = 0.15$ [0.00-0.40]) main effects demonstrated large effect sizes. There were no significant interaction effects for ΔHHb in the TB during the bicep curl ($p > 0.05$) (Table 6.13).

For the BB in the close grip bench press there were no significant main effects for ΔTSI ($p > 0.05$). There were also no significant interaction effects for ΔTSI in the BB for the close grip bench press ($p > 0.05$). For the TB in the close grip bench press there were no significant main effects for ΔTSI ($p > 0.05$). There was a significant time by somatotype interaction effect ($F[1, 14] = 12.41$, $p < 0.01$, $\eta_p^2 = 0.47$ [CI 0.12-0.65]). The mesomorph group showed a decrease in ΔTSI over 8-weeks, whilst the

ectomorph group showed an increase (Table 6.14). There no further significant interaction effects for ΔTSI in the TB during the close grip bench press ($p > 0.05$).

Table 6.13: Mean (± SD) ΔHHb for the upper body exercises and muscles during control and training periods (μM)

Exercise	Muscle	Time point	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
			Training	Control	Training	Control
Close grip bench press	Bicep Brachii	0 weeks	1.49 (± 1.22)	4.25 (± 5.19)	2.20 (± 3.71)	-0.97 (± 10.27)
		8 weeks	3.19 (± 2.86)	1.41 (± 1.58)	2.77 (± 7.40)	-0.16 (± 2.78)
	Triceps Brachii	0 weeks	-0.30 (± 3.19)	-0.36 (± 7.24)	7.65 (± 5.67)	2.07 (± 14.52)
		8 weeks	3.28 (± 5.73)	0.84 (± 4.84)	-0.09 (± 11.04)	5.42 (± 7.97)
Bicep curl	Bicep Brachii	0 weeks	2.43 (± 3.97)	7.24 (± 6.08)	6.58 (± 9.77)	-0.68 (± 12.60)
		8 weeks	7.25 (± 6.49)	2.40 (± 3.55)	10.89 (± 14.37)	6.47 (± 4.65)
	Triceps Brachii	0 weeks	1.98 (± 3.96)	0.28 (± 1.85)	3.10 (± 4.62)	-8.20 (± 17.16)
		8 weeks	4.78 (± 7.09)	2.66 (± 5.96)	4.63 (± 17.48)	2.01 (± 4.19)

For the BB in the bicep curl there were no significant main effects for ΔTSI ($p > 0.05$). There were also no significant interaction effects ($p > 0.05$), although the time by somatotype interaction demonstrated a large effect size ($\eta_p^2 = 0.15$ [CI 0.00-0.39). For the TB in the bicep curl there was a significant condition main effect for ΔTSI ($F[1, 14] = 4.91$, $p < 0.05$, $\eta_p^2 = 0.26$ [CI 0.00-0.50]). There was a greater decrease in ΔTSI in the training condition versus the control (Table 6.14). There was also a significant time main effect ($F[1, 14] = 7.63$, $p < 0.05$, $\eta_p^2 = 0.35$ [CI 0.04-0.57]). There was a lower ΔTSI in the post training period compared to the baseline. There were no significant interaction effects for ΔTSI in the TB during the bicep curl ($p > 0.05$).

Table 6.14: Mean (± SD) ΔTSI for the upper body exercises and muscles during control and training periods (%)

Exercise	Muscle	Time point	Mesomorphs (N = 8)		Ectomorphs (N = 8)	
			Training	Control	Training	Control
Close grip bench press	Bicep Brachii	0 weeks	-2.26 (± 2.08)	-3.75 (± 12.54)	-2.83 (± 5.83)	-3.59 (± 5.91)
		8 weeks	-4.42 (± 7.46)	-1.82 (± 3.44)	-6.65 (± 12.02)	-1.48 (± 4.79)
	Triceps Brachii	0 weeks	-0.04 (± 10.56)	-2.36 (± 11.87)	-11.00 (± 10.48)	-12.80 (± 8.73)
		8 weeks	-9.39 (± 12.17)	-6.90 (± 6.83)	-3.35 (± 6.44)	-7.97 (± 9.38)
Bicep curl	Bicep Brachii	0 weeks	-7.22 (± 6.97)	-7.97 (± 6.08)	-1.18 (± 16.63)	-9.22 (± 16.79)
		8 weeks	-7.12 (± 11.99)	-4.75 (± 6.91)	-9.77 (± 12.43)	-11.13 (± 8.14)
	Triceps Brachii	0 weeks	-2.98 (± 6.03)	2.54 (± 13.08)	-4.06 (± 6.49)	-0.68 (± 5.19)
		8 weeks	-5.07 (± 6.19)	-4.53 (± 9.46)	-11.33 (± 9.93)	-5.15 (± 5.68)

6.4.5 Calories and activity

There was no significant condition or somatotype main effect for calorie intake during the study period ($p > 0.05$). There was also no significant condition by somatotype interaction effect ($p > 0.05$). There was a significant condition main effect for daily activitiy intensity (AU) ($F[1, 14] = 7.34$, $p < 0.05$, $\eta_p^2 = 0.34$ [CI 0.04-0.56]), representing an overall increase in the activity intensity in the training condition compared to the control (Table 6.15). There was no significant somatotype main effect and no significant condition by somatotype interaction effect ($p > 0.05$). There was no significant difference in the average per session training volume between the two somatotype groups for the 8-week resistance training period ($p > 0.05$).

Table 6.15: Calorie intake, daily activity and training volume across the training periods (mean ± SD)

	Mesomorphs (N = 8)		**Ectomorphs (N = 8)**	
	Control	**Training**	**Control**	**Training**
Calorie Intake (kcal·kg body mass^{-1})	45.0 ± 6.9	46.7 ± 6.4	44.3 ± 7.1	45.7 ± 7.2
Daily Activity Intensity (AU)	1.88 ± 0.85	2.01 ± 0.90	1.74 ± 0.59	2.10 ± 0.63
Training Volume (Average per session, kg)	N/A	7384.4 ± 945.4	N/A	7236.9 ± 801.4

6.5 Discussion

The main findings of this study indicate that the 8-week training period induced significant increases in both relative strength (for all exercises) and relative MT (for all muscles) compared to the control period irrespective of somatotype. The key differences between mesomorphs and ectomorphs relate to the ectomorph group's superior ability to develop relative back squat strength, and the mesomorph group's superior hypertrophy in the TB and BF muscles. Somatotype, as represented by the SAD, demonstrated no significant change over the training period but there was a significant difference between the somatotype groups. Mesomorphy ratings were significantly positively correlated to hypertrophy in the BB, TB and BF muscles, whilst ectomorphy ratings were significantly negatively correlated to these muscle groups. Secondary measures of EMG and NIRS were unable to provide clear and consistent mechanistic reasons for the observed patterns of change. Despite this, there is a difference in the way that ectomorphs and mesomorphs respond to a resistance training programme over 8 weeks.

The lack of significant change in somatotype over the training period indicates a relative stability of somatotype even in the face of changes in muscle architecture. This is supported by previous

research demonstrating a minimal change in somatotype components over a 6-month period in professional football players (Casajus, 2001), and supports stability in the correct categorisation of participants throughout the current research.

6.5.1 Strength

The mean relative increase in 10RM strength was higher in the ectomorphy group than the mesomorphy group for back squat (70.0% vs 43.6%, respectively), but higher in the mesomorphy group than the ectomorphy group for close grip bench press (34.4% vs 25.0%, respectively), and bicep curl (50.0% vs 26.1%, respectively) during the resistance training period. Non-training periods demonstrated relative group mean changes in the range -5.3% to 11.1%, which is within, or slightly below the reported daily variation in strength output of 10-20% (Poliquin, 1988). In this study, the increase in strength measured via 10RM in the training period is larger than that seen in a similar untrained population measured via upper body machine-assisted 5RM exercise (12.7%; Buresh *et al.,* 2009), lower body isometric testing (21%; Ahtiainen *et al.,* 2003b), lower body isokinetic testing (13%; Holm *et al.,* 2008), lower body machine-assisted 5RM exercise (25.7%; Buresh *et al.*, 2009) or unilateral 1RM leg extension (19%; Ahtiainen *et al.,* 2003b; 36%; Holm *et al.,* 2008). However, the current study produced slightly lower relative improvements in back squat strength compared to those in a study by Campos and colleagues (2002) where the untrained participants produced an average 100% increase in 1RM back squat strength from baseline when following a similar training programme to the current study over 8 weeks. However, this magnitude of improvement was only seen in the previous research in the low repetition group who performed 3-5 RM for four sets with 3 minutes rest between sets, which may explain the greater strength development compared to the current study. Testing methods and training protocol design appear to be the main determinants of relative strength improvements, with the current study supporting observations of lower and upper body strength increases in all untrained participants over an 8-week period when training for 3 days per week (Abe *et al.,* 2000; Holm *et al.,* 2008). It is also possible that the use of free weight protocols in the current study (and that by Campos *et al.,* 2002) induce a greater improvement in relative strength due to a higher rate of neurological development than those using machine weights such as Ahtiainen *et al.* (2003b) and Holm *et al.* (2008), although research is largely unsupportive of this view (Sanders, 1980; Silvester and Bryce, 1981; Boyer, 1990). The latter author suggests that it is more likely the similarity between the training method and the testing method (i.e. testing 10RM for the exercises used in the training programme) that supports a larger observation in strength improvement. In the current study participants were tested with the same exercises, using the same

free weights and over the same repetition range utilised throughout the training programme. This may, in part, explain the large relative strength increases observed.

The current study demonstrated a significant difference between ectomorphs and mesomorphs in relative 10RM back squat strength improvement over the 8-week training period. In Chapter 3 of this thesis, it was demonstrated that a combination of high mesomorphy and ectomorphy ratings were superior for baseline back squat strength performance with a 3RM protocol (Ryan-Stewart *et al.*, 2018). This is further supported by results from Saha (2014) who demonstrated positive correlations between mesomorphy and ectomorphy, and leg explosive power. In the current population, the ectomorphy group had an average mesomorphy rating of 3.3 and an average ectomorphy rating of 4.2. Both of these values are considered moderate in the somatotype rating scale (Carter, 2002). Meanwhile, the mesomorphy group had an average mesomorphy rating of 5.8 (high) and ectomorphy rating of 2.1 (low). It may be that the combination of moderate mesomorphy and ectomorphy ratings in the ectomorphy group was more favourable for strength development in the back squat against the low ectomorphy rating of the mesomorphy group.

6.5.2 Hypertrophy

The training period resulted in significant increases in MT measures via ultrasound and anthropometric measures of arm girth compared to the control period. This suggests that in the untrained population used in the current study, the training programme was sufficient to induce hypertrophy over an 8-week training period. This is supported by research by Wilkinson and colleagues (2006) who also demonstrated early hypertrophy in a unilateral training programme lasting 8 weeks, with increases in muscle CSA (5.4%) measured with CT scans. Some studies have also shown ealier hypertrophy, demonstrating increases in muscle size in the first few weeks of a resistance training study (Abe *et al.,* 2000; Seynnes *et al.,* 2007; DeFreitas *et al.,* 2011; Ogasawara *et al.,* 2012; Arazi *et al.*, 2013). A resistance training study that doesn't specifically focus on hypertrophic development can develop muscle mass over 8 weeks in untrained male participants.

There were significant differences in relative change in MT in the TB and BF between somatotype groups over the 8-week training programme with the mesomorphy group experiencing a greater relative hypertrophic response than the ectomorphs (TB 14.9% vs 2.6%; BF 11.2% vs 3.4%). Although not significant the mesomorphy group also experienced larger relative increases in BB (8.4% vs 5.1%)

and RF (8.7% vs 4.1%) than the ectomorphy group. These observations are supported by positive significant correlations between relative change in BB, TB, and BF MT and mesomorphy rating, and significant negative correlations between the relative change in the same muscles and ectomorphy rating. The increases in MT in the current study are similar to observations in muscle cross-sectional area observed via various scanning techniques in studies with similar programmes (Cureton *et al.,* 1988; Seynnes *et al.,* 2007; DeFreitas *et al.,* 2011). MT measures via ultrasound of the TB and BB in a study by Ogasawara and colleagues (2012) were lower at 9 weeks than in the current study (TB 12.3%; BB 0.4%). This may be a result of different training volumes, with only free weight bench press being utilised in the former study. The absolute stress applied to a muscle is best represented by the number of sets per muscle group (Peterson *et al.,* 2005). In the current study, two exercises (CGBP and BB) were conducted to target the upper arm muscles. Given research indicates that higher volume programmes result in significantly greater hypertrophy, specifically in elbow flexors (Schoenfield *et al.,* 2019), the higher volume experienced by those muscle groups in the current study is evidenced by a higher hypertrophic response. Physique is also rarely considered in previous training studies and, given the results of the current study, the inclusion of ectomorphs in those study populations may attenuate the population average reported for hypertrophy.

The difference in hypertrophy experienced by the TB and BF muscles between somatotypes indicates that mesomorphs have a superior ability to build muscle over ectomorphs when exposed to the same training programme in those particular muscles. In his 1970 paper reviewing the somatotype of athletes, Carter indicated that those athletes with a predominance towards ectomorphy are often involved in endurance-based events that require a strong aerobic profile. It is possible, therefore, that ectomorphs possess a greater number of Type I muscle fibres to support an aerobic profile than those who are naturally mesomorphic. Previous research has reported the greatest hypertrophy rates in untrained individuals to occur in type IIa fibres (20-45%; Staron *et al.,* 1990; Campos *et al.,* 2002;) compared to only 10-31% in type I fibres (MacDougall *et al.,* 1980; Campos *et al.,* 2002;). Whilst the muscle fibre profile of the current participants is not known, this could be an important future area of inquiry to assist in explaining the different rates of hypertrophy observed.

The TB and BF muscles were particularly exposed to additional eccentric movements through the Nordic curl, bicep curl and close grip bench press exercises during the training programme. Research has demonstrated that eccentric loading can bring about significantly greater hypertrophy than

concentric loading (Higbie *et al.,* 1996; Farthing and Chilibeck, 2003; Friedmann *et al.,* 2004; Norrbrand *et al.,* 2008). This is considered due to a greater level of disrupted contractile, structural and supportive elements via eccentric muscle action compared to concentric action (Enoka, 1996). A meta-analysis on this topic indicated that whilst the advantage of eccentric training for hypertrophic development was relatively small, there was still a greater increase in muscle size with eccentric training compared to concentric training (10% vs 6.8%; Schoenfield *et al.,* 2017). This is supported in the current study through the greater relative increases in MT in those muscles particularly exposed to eccentric loading. This may have contributed to the differences observed between somatotype groups. In fact, it is possible that those in the ectomorphy group do not experience the same hypertrophic response to eccentric loading as the mesomorphy group. This would be another interesting future area of inquiry.

The relative increase in both CRAG and RAGFT was, on average, in the region of 3% for both somatotype groups over the training period (compared to a change of roughly 1.5% in the control period). This training increase was a smaller relative increase than that seen in the study by Cureton *et al*. (1988) of 7.9%, although apparently occurring at a similar rate since the latter study was carried out over 16 weeks. In a study of the same duration to the current study, Arazi *et al.* (2013) demonstrated a slightly greater amount of upper arm hypertrophy at 5.5% despite participants training for the same number of days per week. The description of upper arm circumference measurement in that study is not clear and also does not appear to be standardised in the same way as the ISAK (Stewart *et al.,* 2011) protocols used in the current research. Volume and linearity aspects of the Arazi and colleagues (2013) training programme were also noticeably different to the current study and may also have contributed to the larger arm circumference increases seen in their study. There were no significant differences between somatotype groups for CRAG and RAGFT in the current study. In light of the differences and relationships observed in MT measures this would suggest that surface anthropometry may lack the sensitivity required to observe differences at the muscular level (Phillips, 2000).

6.5.3 EMG

Explanation for the difference in relative back squat strength between somatotype groups in the current study is not supported by differences in back squat EMG signal PAm or TTP or changes in these values. This is supported by previous research indicating no direct relationship between EMG signal value and changes in strength (Hakkinen *et al.,* 1987). However, contrasting studies suggest

that resistance training does induce increases in EMG amplitude (Aagaard *et al.,* 2002; Van Cutsem *et al.*, 1998), which also appears to be the case in the current study. In particular, PAm increased significantly over the 8-week training period in the RF eccentric contraction during the back squat exercise and in the TB eccentric contraction in the close grip bench press. Research indicates that in untrained participants eccentric EMG activity is reduced, but that large improvements can be seen in eccentric activity with resistance training (Aagaard *et al.,* 2000). This is supported by the results from the RF and TB muscles in those particular movements. There was also a significant large positive correlation between absolute change in bicep curl strength and change in PAm in the BB during both the concentric and eccentric phase of the exercise, as well as between absolute change in back squat strength and change in PAm in the RF during the concentric phase of the back squat. This could indicate that enhancements in neurological function over the training period contributed to improvements in strength output in the sample population (Moritani and DeVries, 1979; Williams *et al.,* 2017).

The only significant difference between the somatotype groups in PAm was in the TB during the concentric phase of the bicep curl, with the mesomorph groups demonstrating an increase over training (+ 0.60 mV) and the ectomorph group demonstrating a decrease (- 0.16 mV). Combined with the observations of a significant difference in TB MT between the two groups this suggests that the mesomorph group experienced both positive hypertrophic and enhanced motor unit recruitment contributing to an increase in bicep curl strength over the 8-week training period. Although the ectomorph group did increase their bicep curl strength during the training programme, the increase was approximately half that seen by the mesomorph group and this may be a result of a combination of reduced hypertrophic response and little or no change in motor unit recruitment. However, caution should be exercised when interpreting PAm since the outcome measure does not allow for complete understanding of the complex recruitment of motor unit recruitment or rate coding (Aagaard, 2003). It is difficult, therefore, to ascertain what the exact changes in motor unit recruitment may be in the current population.

The pattern of results in TTP in the current study does not appear to offer any clear explanations, although the pattern of increased TTP in various muscles during eccentric contractions in the mesomorph group following training may be a reflection of a reduction in antagonist muscle action as strength output increased (Moritani, 1979).

6.5.4 NIRS

The results from the NIRS analsis were largely unclear from a somatotype comparison perspective. There was a significant difference in the ΔO2Hb during the close grip bench press in the BB and the bicep curl in the TB between somatotype groups. This may indicate some adaptations in the metabolic response to those particular muscles during those particular exercises. Previous research utilising blood flow occlusion has indicated that hypertrophy might occur more favourably in those muscle that experience a transient hypoxic environment (Viru *et al.,* 1998; Takarada *et al.,* 2000; Abe *et al.,* 2005). In this case, it would appear that the mesomorph group were beginning to adapt to a more oxygen-rich response to those exercises, with the ectomorph group shifting to a more hypoxic response after 8-weeks of resistance training. It is possible that with a longer study duration, the ectomorph group may begin to demonstrate an enhanced hypertrophic response from an increase in transient hypoxia (Abe *et al.,* 2005). However, the current study failed to identify any consistent patterns or differences in any of the other measured NIRS variables either via training or between somatotype groups. The magnitude of standard deviations seen among NIRS variables in the current study would seem to suggest that these characteristics are heterogeneous in nature and metabolic responses to resistance exercise vary greatly between individuals.

6.5.5 Calories and activity

Additional data was collected on participants' nutrient intake, physical activity and overall training volume during the training period. There were no significant differences between somatotype groups in any of these elements. Nutritional intake, in particular, can be important when considering muscle hypertrophy because of its direct impact upon the balance of protein synthesis or degradation and therefore to muscle building capacity (Volek, 2004). In the absence of additional nutritional intervention this study was able to support the notion that resistance exercise alone creates a physiological response that results in hypertrophic development (Kraemer *et al.,* 1990). There was a significant increase in activity intensity between the two conditions, but this is likely due to the addition of the resistance training programme and did not differ between the two somatotype groups.

6.5.6 Strengths and Limitations

A key limitation to the current study lies in the lack of explanation provided to the strength and hypertrophy differences observed from additional data in EMG and NIRS. Although some differences were observed, these were not consistent and so didn't offer a clear pattern of explanation. However, research does recognise that a difference in EMG activity post-training can be difficult to observe due to changes in skin and muscle tissue properties that result from the training (Aagaard, 2003). This may also be the case for NIRS, where research has demonstrated a consistent relationship between subcutaneous fat and NIRS outcome measures (Matsushita *et al.,* 1998; van Beekvelt *et al.,* 2001). Whilst NIRS has established good test-retest reliability during dynamic activities previously (van Beekvelt *et al.,* 2002; Pereira *et al.*, 2005; Tanimoto and Ishii, 2006), this does not account for changes in skin and muscle that may be observed during a training programme. Future research should look to establish this relationship further. Despite the absence of any clear patterns in the subsidiary data, this study conducted a robust exploration of the mechanisms behind the training-induced adaptations through NIRS and EMG analysis.

Another important consideration is the lack of extreme ectomorphy ratings in the current study population. Whilst the highest mesomorphy rating was 9.4 (extremely high), the highest ectomorphy rating was 4.9 (moderate) (Carter, 2002). This may have created an imbalance in the populations such that the extremities of the mesomorphy responses to resistance training of this nature were observed, but not those of the extremities of ectomorphy ones. This is also reflected in the SAMs of the two groups, which was considered large for the mesomorph group (3.0) and small for the ectomorphy group (0.7) according to Carter *et al.* (1997). This suggests that a broad range of mesomorphs were included in the study population, but that the ectomorph group were relatively homogenous (Carter *et al.,* 1983). It is possible, in fact, that the differences in strength and muscle development observed between the two groups are larger than this study is able to demonstrate with the limited ectomorphy ratings.

The strong technical skills of the current investigator in anthropometric measures are recognised through the low technical error scores in the somatotype measurements. This has resulted in a good established reliability for somatotype ratings in the current research. Even then, recognition that some participants may fall slightly outside of their established dominant group is evident, although with low technical error dominance is still attributed to the originally assigned category. Measures of

MT are also considered reliable (Chapter 4), and so in the current study can be considered a true representation of the hypertrophic response demonstrated over the training period.

The current study was designed in a robust manner with a cross-over to allow for the normal variation in measured variables to be assessed over the same time period as the training programme. The aim of this cross-over design was to take into account random within-subject variation in strength, MT, NIRS and EMG measures (Williamson *et al.,* 2017) in order to assess the true magnitude of change in the training period.

The training programme presented in this study was 8-weeks in duration and was of sufficient length and volume to demonstrate adaptive responses in muscle size and strength in untrained ectomorphs and mesomorphs. This supports observations of the time-course of these adaptations by previous researchers (Abe *et al.,* 2000; Campos *et al.,* 2002; Ahtiainen *et al.,* 2003b; Ahtiainen *et al.,* 2016).

6.6 Conclusion

There were significant improvements in strength outputs across the population during the training programme. The ectomorph group experienced superior improvements in relative strength in the back squat possibly due to the favourable combination of ectomorph-mesomorph rating seen in this population. This resulted in a rejection of the hypothesis that mesomorphs would develop superior strength over the training programme. There were significant differences in the rate of hypertrophy demonstrated in the triceps brachii and biceps femoris muscles, favouring the mesomorphic participants, failing to reject the hypothesised outcome that mesomorphs would experience superior hypertrophy. However, the magnitude of hypertrophy experienced did not appear to be related to any changes in strength output. Subsidiary measures of EMG and NIRS were unable to offer consistent explanation as to the differences seen between somatotype groups, although there may be some differences in motor unit recruitment activitiy and metabolic response to exercise between the two somatotype groups. In particular, the timecourse for an optimal hypoxic environment may be delayed in the ectomorphic population such that a longer training programme may be required to demonstrate significant hypertrophy in this population. The hypothesis relating to significant differences in EMG and NIRS measures between mesomorphs and ectomorphs, therefore, is rejected.

Overall, this study indicates that somatotype has an influence over resistance training response. While the mechanisms for the different responses in the current study remain elusive, it seems that prescription of a standard resistance training regime will result in different outcomes for mesomorphic untrained males versus ectomorphic untrained males. Further research is required to understand if ectomorphs can achieve hypertrophy to the same extent as mesomorphs with altered training prescription (e.g. greater volume) or an extended training period. It may simply be that ectomorphs are limited in their hypertrophy but not in their strength development, and that muscle mass differences will persist between the two somatotype groups even with altered training prescription.

Chapter 7: General discussion and conclusion

7.1 Main Findings

The purpose of this thesis was to identify if there was a relationship between somatotype and responses to acute and chronic resistance exercise. The initial finding from this research demonstrate a relationship between somatotype and strength performance before training (Chapter 3). Whilst it is largely recognised in previous literature that mesomorphy is positively related to strength output, this thesis demonstrated a novel positive association to the combination of mesomorphy and ectomorphy with higher lower-body strength output. It was also demonstrated that muscle thickness as measured using B-Mode ultrasound may determine some of the baseline relationship between somatotype and strength output (Chapter 5). The relationship between somatotype and strength adapts when examining resistance-training induced changes, and there is a clear predominance for mesomorphs to experience a higher rate of training-induced hypertrophy than ectomorphs (Chapter 6). Despite this, ectomorphs can still develop similar improvements in strength performance (Chapter 6). This finding may contribute to the narrative of training-induced strength improvements in the absence of hypertrophy. The thesis has been unable to attribute the muscular changes during training to differences in the neuromuscular or metabolic adaptations during the training process (Chapter 6).

7.1.1 Prediction of strength output and morphology

The primary focus of two studies of this thesis (Chapters 3 and 5) was to establish relationships between somatotype ratings and resistance exercise variables (strength, hormonal response, muscle thickness). Taken together the results of these studies indicate that somatotype rating has an influence on anaerobic (particularly strength) tasks and that some of this influence is related to differences in muscle architecture. In particular, mesomorphic ratings are positively associated with upper and lower body strength and muscle size at baseline in the untrained population. Ectomorphy rating, meanwhile, is negatively associated to these same variables (although not significantly based on the Bonferroni corrected *p* value). The support for these observations in previous literature is considerable, with the strong musculo-skeletal development demonstrated by mesomorphic athletes resulting in success in many strength- or power-based sports (Tanner, 1964; Ergen *et al.*, 1985; Rodriguez, 1986; Kuzmicki and Charzewski, 1987; Carter and Health, 1990; Charzewski *et al.*, 1991; Fagerlund and Hakkinen, 1991; Slater *et al.,* 2005; Lewandowska *et al.,* 2011). The link to muscle mass is intuitive, stronger individuals normally having larger muscle masses (Siders *et al.,* 1993; Fukunaga *et al.,* 2001; Olds, 2001; Brechue and Abe, 2002; Patterson *et al.,* 2007; Ackland,

2008; MacGillivray *et al.,* 2009; Lieber, 2010; Draper and Marshall, 2013; Saha, 2014). A larger muscle often contains more contractile units, resulting in superior force production (Saha, 2014). Results from Chapters 3 and 5 present a clear relationship between mesomorphs, larger muscles and superior strength performance prior to training.

Since ectomorphy is an indication of a person's slenderness (Carter, 1996) it also seems intuitive that those with a high ectomorphy rating are likely to have smaller muscle measurement. This was also confirmed in the current research (Chapter 6). It is suggested that ectomorphs also have longer limbs than their mesmorphic counterparts, which could predispose them to lower strength and power outputs since short levers are often considered an advantage (Carter, 1970; Lewandowska *et al.,* 2011). Longer limbs have also been associated with smaller pennation angles (Aagaard *et al.,* 2001; Kanehisa *et al.,* 2003), which may lead to reduced force output (Kawakami *et al.,* 1993). There is some support for these observations from the pennation angle results in Chapter 4 since the majority of muscles in the ectomorphy participants in this study had lower pennation angles than the mesomorphy group, although results cannot be compared confidently due to poor reliability for that measure in the current thesis. However, the novel finding from the baseline analysis in the current research is that when ectomorphy rating is considered alongside mesmorphy rating it can be seen as advantageous to lower body strength output (Chapter 3). The regression model suggests that as mesomorphy rating increases by 1 unit, 3 RM squat performance will increase by 19.8 kg, and as ectomorphy increases by 1 unit (e.g. moves from somatotype 2-3-5 to 2-3-6), 3 RM squat performance will increase by 10.0 kg. The combination of mesomorphy and ectomorphy somatotype ratings predicts 38.8% of lower body strength performance in the current study. It is possible that the addition of gravitational support to a movement such as the back squat favours the combined linearity and musculo-skeletal robustness of an ecto-mesomorph profile. Previous research supports this in positively linking ectomorphy and explosive leg power (Marta *et al.,* 2011; Busko *et al.,* 2013; Saha, 2014). The results from the current research alongside support from previous research into multivariate analysis and somatotype observations (Peeters *et al.,* 2007) suggest that there could be more value in utilising a participant's whole somatotype profile (or at least mesomorphy and ectomorphy ratings) to predict strength performance particularly in the lower body. The value of predicting strength output is particularly relevant in clinical settings, where the comparison of actual strength output to predicted can help in diagnosis of particular conditions and production of training programmes for those individuals (Usa *et al.,* 2017). Somatotype of those individuals, therefore, should be taken into consideration when predicting an individual's strength outcome.

There are multiple factors that contribute to a person's body composition, which can be largely grouped into genetic and environmental contributions as outlined by the theory of probabilistic epigenesis (Gottlieb, 2007). These influences may always be a limitation to somatotype research as it is difficult to ascertain the level of environmental influence over a person's somatotype rating at any particular time point. Indeed, this has created much debate in the literature examining physique and sporting success, with uncertainty in identifying whether training or natural selection has determined success in those sports (Medved, 1966; Stepnicka, 1986). Somatotype itself will be influenced by prior exposure to neural, behavioural and environmental events (Gottlieb, 2007). Mesomorph and ectomorph components are considered to be the most strongly heritable aspects of somatotype (Peeters *et al.,* 2007), which helps strengthen observations surrounding these ratings in this research. It is also clear that somatotype does not completely predict strength performance (in Chapter 3 it predicts around one third of strength performance), and that other factors should also be considered. These factors can include warm-up (Kokkonen *et al.*, 1998; Nelson and Kokkonen, 2001; Rubini *et al.*, 2007), psychological characteristics (Wilkes and Summer, 1984; Murphy *et al.*, 1988; Wright and Smith, 2011), and nutritional status (Leveritt and Abernethy, 1999; Goldstein *et al.,* 2010). However, the strong relationships between somatotype and baseline strength performance, plus observations surrounding muscle thickness, indicate that somatotype should be a consideration when assessing strength outputs and predicting performance in strength-based sports.

Early work indicated that endomorphic ratings contributed to superior strength and power measures when combined with mesomorphy (Bale *et al.*, 1984; Quarrie *et al.,* 1996). These observations are not supported in the current research, with endomorphy demonstrating no significant relationships with the measured strength or muscle architecture variables. In contrast to mesomorphy (86%) and ectomorphy (67%), endomorphy (28%) has a low heritability estimate (Peeters *et al.,* 2007). It is possible, therefore, that environmental influences such as physical activity and diet have influenced the somatotype rating of those ranked dominant in the endomorphy group, and thus masking a true dominance in one of the other two ratings. Given that previous research has indicated endomorphy to have a negative impact on performance (Willgoose and Rogers, 1949; Kuzmicki and Charzewski, 1987; Charzewski *et al.*, 1991; Fagerlund and Hakkinen, 1991) it may be important to fully understand how a high endomorphic rating might impact on different performance factors. Although for strength performance in the current population, there appears to be no implication.

7.1.2 Responses to training

7.1.2.1 Acute Responses

Structured resistance training aims to disrupt the body's homeostasis in order to adapt and bring about a higher functional ability (Koutedakis *et al.,* 2006). Acute functional responses following resistance training can be categorised into neurological or metabolic/hormonal. In the final study of this thesis (Chapter 6), acute response data was collected for all participants over three different sessions (2 control period [pre, end], 1 baseline training [pre]) for both categories of acute responses. The findings of Chapter 5, where acute responses to resistance exercise in salivary hormones were measured, can be combined with these observations to assist with the metabolic/hormonal components of adaptation. Acute responses to resistance training may be able to offer some explanation to longer term hypertrophic or strength changes (McCall, 1999; McCall *et al.,* 1999; Hakkinen *et al.,* 1998; 2001a; Hansen *et al.,* 2001; Nindl *et al.,* 2001; Migiano *et al.,* 2009; Ronnestad *et al.,* 2011).

The amplitude of an EMG signal is a quantification of muscle activation since it often reflects the number and firing rate of motor units in the muscle (Marek *et al.,* 2005). Early research suggests that muscle force and EMG are closely related (Hof, 1984), and so it may be expected that those who can produce higher strength outputs would have higher EMG amplitudes. This theory is not supported from results in the current research since there were no obvious and significant differences in baseline EMG characteristics between somatotypes despite mesomorph's superior strength output. However, research has suggested that complete understanding of the complexity of motor unit recruitment cannot be gained by simply analysing peak amplitude (Aagaard, 2003). During the control period EMG peak amplitude was highly variable both within and amongst participant groups, and is probably a reflection of a complexity of recruitment patterns in the muscles of individual participants. For certain muscles the mean change in PAm observed during the control period was higher than that observed over the training period, indicating that it is not simply training variables that influence PAm measures from EMG and can also be a result of differences in skin and muscle tissue properties and electrode placement between sessions (Aagaard, 2003).

Results from NIRS analysis in Chapter 6 coupled with the salivary hormone analysis in Chapter 5 indicates that there is no obvious difference in the way those of different somatotypes respond acutely to resistance exercise. The large standard deviations observed in NIRS parameters suggest that these responses are heterogenous. This heterogenous response is similar to that observed in

studies investigating the hormonal response to resistance exercise, although in contrast to the current research this was amongst trained participants (Hakkinen *et al.*, 1987; Kraemer *et al.,* 1990; Jensen *et al.,* 1991; Kraemer *et al.,* 2001; Di Luigi *et al.,* 2003; Smilios *et al.,* 2003; Beaven *et al.*, 2008; Crewther *et al.* 2009). Testosterone influences both protein synthesis and neurological adaptation of muscle (Mooradian *et al.,* 1987; Staron *et al.,* 1990; Crist *et al.,* 1991; Staron *et al.,* 1994), and so those who naturally respond with higher levels of testosterone would be predisposed to higher levels of hypertrophy and strength development. In fact, previous research has demonstrated a strong positive relationship between baseline testosterone concentration and changes in strength (Ahtiainen *et al.,* 2003b), and exercise-induced changes in testosterone concentration and changes in strength (Ronnestad *et al.,* 2011). Given that there were no significant differences in baseline testosterone concentration or change in testosterone between somatotypes, the potential development of testosterone-mediated strength output should be similar across somatotypes. A similar observation could also be made for hypertrophy since exercise-induced testosterone increases are concurrent with increases in muscle cross-sectional area (Ronnestad *et al.,* 2011). However, research in this area is equivocal with other studies demonstrating no relationship between acute testosterone measures and adaptations to resistance training (Wilkinson *et al.,* 2006; West *et al.,* 2009; West and Phillips, 2012). Previous research has indicated that acute hormonal responses may have little influence over strength development and hypertrophy over a longer-term training regime (West and Phillips, 2012).

Muscular adaptation may be mediated by hormonal changes (Beaven *et al.*, 2008), although given the heterogeneous response in the current study population the exact nature of this mediation remains unclear. The results from this study support the uncertainty that surrounds the biological role of hormone changes in response to resistance exercise (West and Phillips, 2012). Acute hormonal responses to resistance training may have an important regulatory mechanism surrounding protein metabolism during recovery (Kraemer *et al.,* 1992; Kraemer and Ratamess, 2005). In the current study, it may be that the change in T:C is a demonstration of this regulation, with a conservation of T concentration compared to C concentration, prioritising protein anabolism during recovery from this particular resistance protocol. Although, protein metabolism, muscle growth and strength may not be governed by hormones elevated physiologically in untrained participants (Wilkinson et al., 2006; Buresh *et al.*, 2009; West *et al.,* 2009; 2010). Previous research utilising blood flow occlusion has indicated that hypertrophy might occur more favourably in those muscles that experience a transient hypoxic environment due to the impact of muscle oxygenation status on growth hormone (Viru *et al.,* 1998; Takarada *et al.,* 2000; Hoffman *et al.,* 2003; Abe *et al.,*

2005). The baseline NIRS observations in the current research fail to identify any significant differences in the oxygenation status of the muscle during resistance exercise between somatotype groups. Growth hormones were also not measured here, but could be stronger predictors of muscle hypertrophy than testosterone or cortisol.

7.1.2.2 Chronic responses

The increase in strength output and muscle size experienced during resistance training is well-established (Ahtiainen *et al.,* 2003a; West and Phillips, 2012), and is strengthened further by the results from the current research. In the final study (Chapter 6), strength output and muscle size increased in both mesomorphs and ectomorphs, particularly compared to the control period. But the most novel finding here was the difference in these variables between somatotype groups. Mesomorphic participants experienced higher relative amounts of hypertrophy, but ectomorphs were able to improve their back squat strength superiorly to their mesomorphic counterparts.

The final study of this thesis (Chapter 6) supports the notion that, over an 8-week resistance training period, ectomorphs have a similar potential to increase strength as mesomorphs. Some of this strength improvement can be attributed to changes in muscle activation characteristics as demonstrated by the strong positive correlations between peak EMG amplitude and change in strength specifically for the bicep curl (bicep brachii concentric and eccentric) and the back squat (rectus femoris concentric). This is in contrast to the observations by Hakkinen and colleagues (1987) who indicated that EMG signal values are not directly related to changes in strength. However, that particular study utilized elite weight-lifters and so differs dramatically from the current study population. In the untrained population, in the specific muscles and during the specific exercises indicated, there does seem to be a link between increase in strength and EMG amplitude. The superior relative increases in strength demonstrated for the back squat in the ectomorph group are not linked to differences in EMG amplitude or time to peak as evidenced in the final study. Previous research suggests that differences in the nature of muscle fibre recruitment (type of fibre recruited), synchronization of motor units and frequency of motor unit firing could all influence strength characteristics (Chilibeck *et al.,* 1998; McBride *et al.,* 2003). Since none of these aspects formed part of the current analysis, it could be that changes in one or more of these aspects explain the relative improvements in back squat strength in the ectomorphic group. The back squat is also a multi-joint, multi-muscle exercise and in this study we only measured activity in the rectus femoris and biceps femoris. It is also possible that changes in muscle activation in other contributory muscles, such as

the vastus lateralis, occurred that could help explain the differences in strength observed (McBride *et al.,* 2003).

Sizable strength outputs are often associated with large muscles (Draper and Marshall, 2013), and in the initial studies of this thesis this is supported; higher mesomorphy ratings are linked to higher strength outputs (Chapter 3) and larger muscle thicknesses (Chapter 5). It could be expected, therefore, that increases in strength seen in the final study are also matched by increases in muscle size. In fact, despite the increases in strength observed by both somatotype groups, there were significant differences demonstrated in the hypertrophic response in certain muscle groups – most notably the triceps brachii and biceps femoris. These specific muscle groups were subjected to the highest eccentric loads during the training programme, which may offer a partial explanation for differences in the hypertrophic response seen (Higbie *et al.,* 1996; Farthing and Chilibeck, 2003; Friedmann *et al.,* 2004; Norrbrand *et al.,* 2008). It is possible that the greater amount of disruption caused to structural components of the muscle with eccentric loading (Enoka, 1996) led to a different response in the mesomorph group compared to the ectomorph group. Those participants with dominant mesomorphic ratings demonstrated a significantly greater increase in muscle thickness at the TB and BF locations compared to those dominant in ectomorphy. This indicates that improvements in strength, at least in the ectomorph group, are not completely related to increases in muscle size. Although Ahtiainen and colleagues (2016) established a significant correlation between increases in muscle strength and size, the size of the correlation was low-medium (Cohen, 1988) indicating that increases in muscle size explain only a small amount of the increase in muscle strength observed during training. West and Phillips (2012) also demonstrated that hormonal responses to resistance exercise have very little association with increases in strength and that muscles do not need to increase in size to become stronger. This perspective may be supported by the current study, where ectomorphs experienced a much smaller hypertrophic response on average but were able to gain similar or greater amounts of relative strength. Mesomorphs and ectomorphs appear to experience different chronic physiological responses in order to develop similar relative amounts of strength improvement. In the absence of any further explanation via measured neuromuscular or metabolic/hormonal adaptations in the current study, further research is warranted to identify the exact mechanism(s) behind these different responses.

7.2 Strengths and Limitations

It is important to contextualise the findings of this research in light of the strength and limitations. Carter (2002) indicates that a somatotype rating is "extremely high" (pp.165 - 166) if it is 7.2 or above. In the current body of research at least one participant rated extremely high was observed in each study for both endomorphy and mesomorphy (even if their dominance lay elsewhere). However, the highest ectomorphy rating achieved was 7.1 (high) in Chapter 4. The lack of extreme values of somatotype, particularly in ectomorphy may limit the extent of the observations provided in this thesis. In particular, the final study found it challenging to recruit those of a strongly ectomorphic physique, with the average somatotype reflecting a push towards a more meso-ectomorphic physique. Analysis of the somatotype data in Chapter 6 indicated that the two study groups were significantly different in their somatotype profile. However, despite this it is possible that the combination of mesomorphic and ectomorphic somatotype ratings enabled the ectomorphy group to experience the hypertrophic and strength-gaining response demonstrated. Investigation into those with more extreme somatotype values at baseline is warranted to establish the full extent of the resistance training-somatotype response relationship.

The strong technical skills of the current investigator in anthropometric measures are recognised through the low technical error scores in Chapter 4. This has resulted in a good established reliability for somatotype ratings in the current research. Even then, recognition that some participants may fall slightly outside of their established dominant group is evident, although with low technical error dominance is often still attributed to the originally assigned category. This could be a concern when grouping participants according to dominant somatotype, but is less of a concern when considering the rating as part of a continuum (as per the correlation analysis). The synthesis of group comparisons and correlations, and the affirmation they offer to the general pattern of results appears to be a strength to the results of this research.

Reliability has been established in the current research for somatotype ratings and muscle thickness measurements such that confidence in the results shown in these variables is high (Hopkins, 2000). Measurement error in some of the other measured variables could be a limiting factor, particularly when considering how these variables change following an intervention (Atkinson and Nevill, 1998). Pennation angle in the current research demonstrated poor-moderate reliability. Previous research has established that strength output and pennation angle are directly related due to the increased contractile unit potential under a higher pennation angle (Kawakami *et al.,* 1993). The current

investigation is limited by the poor reliability of this measure (CVs 31.7-135.0, ICCs 0.32-0.78; Chapter 4), and further research should be undertaken to establish methods to make this measure more reliable by standardising protocols surrounding the probe alignment with the muscle. It could then be possible to establish if a difference in baseline pennation exists between somatotype groups, and if there is a change in this pennation angle following resistance training. A similar observation could be offered to the EMG and NIRS results from the final study, although the large standard deviations observed in these measures may simply be a result of heterogenous responses to the testing sessions. The analysis of peak amplitude in the final study also presents a limitation as it has been recognised this is an oversimplified measure of a series of complex events within the muscle (Aagaard, 2003), which likely contributes to the large intra-individual variation in this measure. More indepth EMG analysis could offer some clarity to the nature of muscle activation changes in the different somatotype groups in future.

Chapter 5 attempted to explain some of the baseline differences in strength between somatotype groups by observing salivary testosterone and cortisol in these groups. The absence of any significant differences supports the notion that biological changes in these hormones may not contribute to resistance training adaptations (West and Phillips, 2012). However, it is recognised that not all potential mediating hormones were observed here, and future research should look to assess baseline, acute and chronic changes in growth hormones in order to assess the full range of hypertrophic hormone influences.

The final study of this thesis (Chapter 6) aimed to demonstrate differences between somatotypes in response to resistance training. In order to determine the true response to resistance training it was necessary to include a control period where participants undertook their normal activity but no resistance exercise. It has been recognised that inter-individual differences in training response may not be as large as first indicated because researchers only take into account the training response measures (Williamson *et al.,* 2017). The final study in this research included a comparison to the control condition such that random within-subject variation in measures of strength, muscle size, EMG and NIRS were taken into account. As such, it can confidently be shown that both strength and muscle size increased following the resistance training more than random within-subject variation can take into account.

The current research focused on untrained participants due to their somatotypes being less likely determined by the environmental factor of prior training (Peeters *et al.,* 2007). Research suggests that training status influences responses to further training (Ahtiainen *et al,* 2003b; Peterson *et al.,* 2005; Williams *et al.,* 2017), and this is an important consideration in the context of application of the current research findings. The observation of different responses to resistance training between mesomorphs and ectomorphs is limited in its application to those who are considered 'untrained' and may be different in people of alternative training statuses. Further inquiry will help to determine these types of relationships.

Although the sample size in the final training study was low (N = 8 in each group), it still met the requirements of the a priori sample size calculation (N = 5 in each group). This is emphasised by the post hoc power values for the significant interaction effects, which were all greater than 0.9. There was also evidence of large effect sizes in many of the interaction effects (Cohen, 1988), including in some that were non-significant. Large effect sizes indicate the results hold practical significance (Kirk, 1996) and indicate the degree to which the results diverge from the null hypothesis (Vacha-Hause and Thompson, 2004). In this final study, then, we can be confident in the results observed.

7.3 Practical applications

Much contemporary literature suggests that exercise prescription should be individualised to maximise an adaptive response (Astorino and Schubert, 2014; Hecksteden *et al.,* 2015; Ahtiainen *et al.,* 2016). However, whilst it is now recognised that the individual response may not be as large as first reported (Williamson *et al.,* 2017), it is also clear that there is further investigation required in understanding inter-individual responses to training (Ahtiainen *et al.,* 2016). Applying training techniques to individuals may require some trial and error, taking significant amounts of time and frustrating those looking to make quick adaptations. The identification of measurable attributes that can help predict training outcomes can help reduce the time taken to prescribe person-specific training. The current research indicates that those untrained individuals of an ectomorphic somatotype are unlikely to develop muscle size from resistance training protocols similar to that used in the final study of this thesis, and so training prescription should recognise this and adjust accordingly. In particular, if muscle size is a desired outcome then ectomorphs may have to adapt training prescription to include higher volume (more sets, more exercises, more training sessions) per week or may have to extend the programme for longer than 8 weeks duration. The latter view is supported by observed patterns in the ΔO2Hb results in the upper body where ectomorphs began to

move towards a negative oxygenation of their muscles during these movements towards the end of the programme, which may suggest it takes longer for them to reach an optimum hypertrophic environment compared to mesomorphs. However, if strength alone is a desired training outcome then a training prescription of a similar nature to that in Chapter 6 would be suitable for both somatotype groups to experience improvements in strength output.

In the United Nations 2019 Revision of World Population Prospects (United Nations, 2019) it is evident that the World's population is experiencing growth in its elderly demographic. Older age often results in disability and disease commonly linked to compromised muscle function (Newman *et al.,* 2006). The term sarcopenia was introduced to refer to loss of lean mass with age in the healthy population (Rosenberg, 1989). However, developments in research in this area have resulted in the term now being more closely related to loss of muscle mass and function (Morley *et al.,* 2001). Further research has rejected this re-classification as the link between strength development and hypertrophy is not clear (as this research shows), so too is the link between muscle loss and loss of strength output (Narici and Maffulli, 2010). It would appear that muscle strength is a more important consideration in the functional ability of the elderly (Visser *et al.,* 2005). Given that this research suggests that muscle strength can be developed in the absence of hypertrophy in a young untrained population, it is possible that this development may also be seen in the elderly. Rather than focusing on the sarcopenic response in this population, it may be more valuable to research those exercise regimes that simply improve functional strength outputs. Since muscle atrophy (or wasting) can also be seen in a wide-range of clinical conditions such as renal disease (Carrero *et al.,* 2008), cancer (Fukawa *et al.,* 2016), and Type 2 diabetes mellitus (Perry *et al.,* 2016), further research is required to establish the link between somatotype and muscle strength characteristics in elderly and clinical populations. If this relationship is similar to that established in the current thesis for untrained persons, then the establishment of clearly defined expected outcomes for those of a mesomorph or ectomorph somatotype in response to resistance training may help to establish functional training programmes for clinical and elderly populations. For ectomorphs, this may involve focusing these training programmes more on establishing functional strength rather than increasing or maintaining muscle mass. Since research has further suggested links between somatotype and clinical risk factors (Bailey, 1985; Gordon *et al.*, 1987; Malina *et al.*, 1997; Katzmarzyk *et al.*, 1998; 1999), somatotype may be an important consideration in the identification and treatment of clinical populations.

7.4 Future research

Research from this thesis establishes clear differences in the way untrained individuals of differing somatotype ratings respond to resistance training. However, this body of work has been unable to establish the underlying mechanisms to these differences. Future research is required in order to achieve this. Primarily, reliability should be established for some of the measures previously indicated; pennation angle, EMG and NIRS to fully understand how these variables change with training in the current population. Further inquiry could also seek to establish any differences in muscle fibre type between those of different somatotypes. This may help further explain differences in hypertrophy rates as observed in the current study, as this has been previously shown to be related to muscle fibre type (MacDougall *et al.,* 1980; Staron *et al.,* 1990; Campos *et al.,* 2002). Evidence is also required surrounding training response of those with extreme somatotype values, particularly in the ectomorphic rating. Finally, whilst this research has demonstrated some clear results with respect to untrained participants, future research should also look to establish any relationship between somatotype and resistance training response in those already exposed to resistance training.

In response to inter-individual responses to training, it has recently been shown that changing the volume, type or intensity of a training programme can result in a positive response in someone who previously didn't respond (Sparks, 2017). It is possible that ectomorphs can experience hypertrophy at a similar rate to mesomorphs, but may need to adapt training variables such as frequency of training, load, recovery, or simply just train for a longer duration in order to achieve this. It may also be, given the relative stability of somatotype seen in the training study of this thesis (Chapter 6) and from previous research (Casajus, 2001), that ectomorphs simply cannot develop muscle mass to the same extent that mesomorphs can. Future research should identify whether this can be achieved if hypertrophic development is a key consideration in someone's training goal.

7.5 Conclusion

In conclusion, this thesis has reinforced that somatotyping is an important contributor to the sport and exercise science knowledge base. In untrained participants, somatotype is linked to strength output, muscle thickness and responses to resistance training. Mesomorphs have an overall higher baseline strength ability, larger muscles and a greater ability to develop muscle mass, particularly compared to ectomorphs. Ectomorphy does contribute to a more positive lower body strength output, and results in a more advanced development of lower body strength over a training

programme than a high mesomorphy rating. Despite this, limited mechanistic evidence has been evidenced in the current research and future research should seek to develop further understanding of the physiological adaptations that differ between the somatotype groups. This may aid in the development of adapted training prescriptions for untrained and clinical populations to address inconsistencies in expected outcome. Somatotype is a reliable method of grouping those of different physiques and can be used to predict strength performance outputs and responses to resistance training in the untrained population.

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Appendix 1a: The influence of somatotype on anaerobic performance

PLOS ONE

RESEARCH ARTICLE

The influence of somatotype on anaerobic performance

Helen Ryan-Stewart*, James Faulkner, Simon Jobson

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Abstract

The link between athlete physique and performance in sports is well established. However, a direct link between somatotype three-numeral rating and anaerobic performance has not yet been reported. The purpose of this study was to assess the relations between somatotype and anaerobic performance using both singular and multivariate analyses. Thirty-six physically active males (mean ± standard deviation age 26.0 ± 9.8 years; body mass 79.5 ± 12.9 kg; height 1.82 ± 0.07 m) were somatotype-rated using the Heath-Carter method. Subjects were assessed for 3 repetition maximum (3 RM) bench press and back squat, and completed a 30-second maximal sprint cycle test. Positive correlations were observed between mesomorphy and 3 RM bench press ($r = 0.560$, $p < 0.001$), mesomorphy and 3 RM back squat ($r = 0.550$, $p = 0.001$) and between mesomorphy and minimum power output ($r = 0.357$, $p = 0.033$). Negative correlations were observed between ectomorphy and 3 RM bench press ($r = -0.381$, $p = 0.022$), and ectomorphy and 3 RM back squat ($r = -0.336$, $p = 0.045$). Individual regression analysis indicated that mesomorphy was the best predictor of 3 RM bench press performance, with 31.4% of variance in 3 RM bench press performance accounted for by the mesomorphy rating ($p < 0.001$). A combination of mesomorphy and ectomorphy best predicted 3 RM back squat performance ($R^2 = 0.388$, $p < 0.04$). Around one third of strength performance is predicted by somatotype-assessed physique in physically active males. This could have important implications for the identification of those predisposed to perform well in sports containing strength-based movements and prescription of training programmes.

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Appendix 1b: Ethics approval letter for study 1 (Chapter 3)

THE UNIVERSITY OF WINCHESTER

Helen Ryan

Department of Sports Studies

University of Winchester

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Helen.Ryan@winchester.ac.uk

21st February 2013

Dear Helen

Re: Ethics Approval

Title: *Does somatotype influence physical fitness outcomes in untrained participants?*

Investigators: Miss Helen Ryan (lead); Dr Simon Jobson

This study was given ethical approval by the Department of Sports Studies ethics panel and the University of Winchester's Faculty of Business, Law and Sport (BLS) Research and Knowledge Exchange (RKE) ethics committee on 20/2/13. Each of the documents identified below have been approved.

APPROVED DOCUMENTS:

- Participant Information Sheet
- Informed consent
- Physical Activity Readiness Questionnaire

This approval is valid for 5 years from the date of this approval.

Best regards

Professor Eric Anderson

Professor Eric Anderson

Department of Sports Studies Ethics Panel

Email: Eric.Anderson@winchester.ac.uk

Appendix 1c: Information sheet for initial exploratory study (Chapter 3)

Participants' Information Sheet, Consent Form & PAR-Q

Title of the Study: *Does somatotype influence physical fitness outcomes in untrained participants?*

Thank you for expressing an interest in this project. Please read the following information sheet ***carefully*** before deciding whether or not to participate in the project. If you choose to participate in the project, we thank you. As a participant, prior to taking part in any testing, you will be required to:

1. Carefully read this ***Information Sheet*** which will outline the procedures and the potential risks to yourself;
2. Complete and sign a ***Consent Form*** and;
3. Complete and sign a ***Physical Activity Readiness Questionnaire (PAR-Q)***

The Consent Form and the PAR-Q can be found at the end of this document.

If you do not decide to participate in the project there will be no disadvantage to you of any kind and we thank you for considering our request.

1. What are the aims of the project?

The aim of this study is to establish if a relationship exists between somatotype and physiological performance in untrained populations. A summary of a person's overall physique is often given using

somatotype. This uses measures relating to body shape and composition, assessing adiposity (fatness), musculo-skeletal robustness, and linearity and is presented as a 3 point rating.

2. What type of participants does the project require?

The present project hopes to recruit an approximate total of 64 untrained but physically active participants.

3. What will the participants be asked to do?

Individuals who volunteer to participate in this project will initially undergo an anthropometric assessment, with relevant measurements (height, body mass, selected skinfolds, girths and bone breadths) being measured by a Level 3 ISAK anthropometrist. This will involve the measurement of subcutaneous skinfolds using Harpenden calipers (triceps, biceps, subscapular, iliac crest, supraspinale, abdominal, front thigh and medial calf), height using a stadiometer, body mass using electronic scales, girths using an anthropometric tape measure (upper arm flexed and tensed, and calf) and bone breadths using bone calipers (biepicondylar humerus and femur). This session will also include measurement of participant's static flexibility at various locations (shoulder joint, lower limb and trunk), and a familiarisation session for 3 repetition maximum (3RM) for back squat and bench press protocols and will last approximately 1-1 ½ hours.

Participants will then be required to return to the University on three separate occasions (separated by at least 72 hours):

1. Session one will involve completion of 3RM assessment for back squat and bench press. This will require participants to lift progressively heavier weights until they are only able to complete three repetitions. Rest periods of 3-5 minutes will be given between lifting attempts. Following completion of the test protocol, subjects will be familiarised with the protocols for lactate threshold and maximal oxygen consumption (VO_{2max}) for the following session. This session will last approximately 1 hour.
2. Session two will involve completion of a lactate threshold and VO_{2max} test on a cycle ergometer. Participants will complete a 5-minute self-paced warm-up. The test protocol will begin at a power output between 50-200 W (depending on capability), with participants

cycling at this intensity for 5 minutes. After each 5-minute stage the intensity will increase by 30 W increments until volitional exhaustion. Heart rate will be recorded throughout the test, whilst expired air will be collected into Douglas Bags during the final minute of each stage. A capillary blood sample from the fingertip will be collected during the last 30 s of each stage and analysed for lactate concentration. This initial protocol should see participants complete 5-7 stages of exercise. Participants will then complete 15 minutes of active recovery at a self-selected pace on the cycle ergometer. The participant will then commence cycling again at a power output 60 W below their final power output in the lactate threshold test. Power output will increase by 20 W per minute (5 W per 15 s) until volitional exhaustion is reached. Heart rate will be collected per stage, and expired air will be collected into Douglas Bags for 1 minute from the fourth stage onwards. This session will last approximately 1 ½ hours. Following the testing procedures participants will be taken through a familiarisation session for the Wingate test protocol.

3. Session three will involve participants completing the Wingate test protocol. The Wingate test involves participants completing a maximum effort for 30 s on a cycle ergometer against a resistance of 7.5% body mass. Participants will complete a 10 minute warm-up prior to the test, and will have a capillary blood sample collected from their fingertip for lactate concentration analysis immediately and 5 minutes post-test. This session will last approximately 1 hour.

4. What are the potential risks and discomforts of the project?

Exercise of any nature can pose a risk to the participant, and as such all necessary precautions will be taken. This will include the presence of a fully qualified First Aider at all testing sessions, and access to a Defibrillator (and necessary trained personnel). Participants may experience some slight discomfort from the efforts involved in the testing. The researcher will ensure that all participants fully understand the procedures involved and the level of discomfort they may feel. Participants will be excluded from the study if they demonstrate any contraindications on the initial PAR-Q.

Collection of capillary blood samples will be part of some of the protocols (specifically lactate threshold test, and Wingate test). Full safety procedures will be adhered to, including the use of protective gloves, and the provision and use of clean and sterile equipment. All samples and contaminated material will be disposed of in the relevant biohazard bins. The collection of a capillary blood sample will cause discomfort similar to a pin prick to the fingertip.

Heavy load resistance exercise such as that completed in the 1RM protocol may pose injury risks to participants, although exact procedures outlined by ACSM (2010) will be followed to minimise these risks. This will also include the use of a squat rack with safety side bars, and the presence of two 'spotters' to assist the lifter should they get into difficulty. Delayed Onset Muscle Soreness may be experienced in the days following the procedure, although the effects are transient and should subside within 72 hours.

5. Can participants change their mind and withdraw from the project?

Individuals may withdraw from participation in the project at any time and without any disadvantage of any kind.

6. What information will be collected, and how will it be used?

Data from the testing procedures described in Section 3 will be collected and used to investigate the influence of somatotype on the various parameters. This data will be stored securely in a lockable filing cabinet in the Department of Sports Studies. Only the Project Supervisor and Investigator will have access to the data. All data will be anonymous and destroyed after a period of five years.

The results of this project may be published, but the information will not be linked to any specific person. A copy of all your personal information, including results, supplement type and dosage will be given to you after completion of testing.

8. What if participants have any questions?

If you have any questions about the project please feel free to contact either:

The Investigator **The Project Supervisor**

Helen Ryan

Lecturer in Sport & Exercise Physiology

Email: Helen.Ryan@winchester.ac.uk

Telephone: 01962 827112

Dr Simon Jobson

Reader in Sport & Exercise Physiology

Email: Simon.Jobson@winchester.ac.uk

Telephone: 01962 827516

Appendix 1d: Consent form for initial exploratory study (Chapter 3)

THE UNIVERSITY OF WINCHESTER

Participant's Consent

I _____consent to take in part in the research study titled:

Does somatotype influence physical fitness outcomes in untrained participants?

The investigator has explained the full details and parameters of all tests and procedures to me, and I have read the Information Sheet. I confirm that I have understood what participation will involve, and confirm that I have been made aware of all the potential benefits and risks of participation.

I declare that I have completed and signed the accompanying Physical Activity Readiness Questionnaire truthfully to the best of my knowledge, and that I have never been advised to abstain from any form of exercise by a medical practitioner. I know of no reason why participation in these testing procedures might present a risk to my safety.

I understand that any medical information that I have submitted will be treated as highly confidential.

I would like to be provided with a copy of the following for my personal records *(please tick)*:

Information Sheet	☐
Consent Form	☐
PAR-Q	☐

Signature _____ **Date _____**

Witness _____ **Date _____**

Appendix 2a: Ethics approval letter for reliability and acute responses studies (Chapters 4 and 5)

THE UNIVERSITY OF WINCHESTER

Helen Ryan-Stewart

Department of Sport and Exercise

University of Winchester

Sparkford Road

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6th November 2015

Dear Helen

Re: Ethics Approval

Title: Comparisons of muscle structure and salivary hormone responses to acute strength training between participants of different somatotype

Investigators: Mrs Helen Ryan-Stewart (lead); Professor Simon Jobson

This study was given ethical approval by the Departmental of Sport and Exercise ethics panel and the University of Winchester's Faculty of Business, Law and Sport (BLS) Research and Knowledge Exchange (RKE) ethics committee on 06/11/15. Each of the documents identified below have been approved.

APPROVED DOCUMENTS:

- Participant Information Sheet_version 1.0
- Informed consent_version 1.0
- Physical Activity Readiness Questionnaire_version 1.0
-

This approval is valid until November 2020.

We wih you all the best for the study.

Dr James Faulkner

Department of Sport and Exercise Ethics Panel

Email: James.Faulker@winchester.ac.uk

Appendix 2b: Information sheet for reliability and non-trained comparisons (Chapters 4 and 5)

THE UNIVERSITY OF WINCHESTER

DSE DEPARTMENT OF SPORT AND EXERCISE

Participants' Information Sheet, Consent Form & PAR-Q

Title of the Study: Comparisons of muscle structure and salivary hormone responses to acute strength training between participants of different somatotype.

Thank you for expressing an interest in this project. Please read the following information sheet ***carefully*** before deciding whether or not to participate in the project. If you choose to participate in the project, we thank you. As a participant, prior to taking part in any testing, you will be required to:

1. Carefully read this ***Information Sheet*** which will outline the procedures and the potential risks to yourself;
2. Complete and sign a ***Consent Form*** and;
3. Complete and sign a ***Physical Activity Readiness Questionnaire (PAR-Q)***

The Consent Form and the PAR-Q can be found at the end of this document.

If you do not decide to participate in the project there will be no disadvantage to you of any kind and we thank you for considering our request.

1. What are the aims of the project?

The aim of this study is to establish if there is a difference in muscle structure (size and architecture) between participants of different physiques (somatotypes). It will further aim to establish if there are any acute differences between physiques in hormonal responses to a single resistance-exercise training session.

2. What type of participants does the project require?

The present project hopes to recruit at least 10 male participants from each somatotype group (endo-, meso-, and ecto-morph). Participants should be between the ages of 18-40 years and have not suffered a recent or past musculoskeletal injury that will impact their involvement in the study. These participants need to class themselves as novice in terms of resistance training i.e. not take part in more than 2 resistance training sessions a week and haven't done so for the past 6 months.

3. What will the participants be asked to do?

Individuals who volunteer to participate in this project will initially undergo an anthropometric assessment, with relevant measurements (height, body mass, skinfolds, girths, lengths and bone breadths) being measured by e a Level 3 ISAK anthropometrist. This will involve the measurement of subcutaneous skinfolds using Harpenden calipers (triceps, biceps, subscapular, iliac crest, supraspinale, abdominal, front thigh and medial calf), height using a stadiometer, body mass using electronic scales, girths using an anthropometric tape measure (forearm, upper arm flexed and tensed, chest, calf, waist, gluteal, thigh [1 cm gluteal], mid-thigh), lengths (upper and lower arm, upper and lower leg) and bone breadths using bone calipers (biepicondylar humerus and femur). Following this participants will then have ultrasound assessment of upper (bicep and triceps) and lower (hamstrings, quadriceps, calves) body muscle groups using B-Wave ultrasound, with images being taken in both the transverse and longitudinal plane. Measures will be taken twice on each location for each participant by two investigators and one two separate occasions to calculate reliability of this measure. At this stage participants will also be required to provide a 3.5 ml saliva sample into a plastic vial via passive drool through a straw to test for baseline cortisol and testosterone concentrations.

Following baseline testing (and in the same testing session if possible) participants will be required to complete a 1 repetition maximum (1RM) assessment of bench press, bicep curl and back squat. This will take part in the Biomechanics laboratory and will involve spotters and the squat rack for safety.

On two further separate occasions, separated by at least 72 hours, participants will be asked to return to the laboratory to undertake a resistance training exercise bout consisting of bench press, bicep curl and back squat prescribed at 65% of 1RM for 10 repetitions and 3 sets with 3 minutes rest between sets. Following the entire resistance training bout, a further saliva sample will be taken via passive drool.

4. What are the potential risks and discomforts of the project?

Exercise of any nature can pose a risk to the participant, and as such all necessary precautions will be taken. This will include the presence of a fully qualified First Aider at all testing sessions, and access to a Defibrillator (and necessary trained personnel). Participants may feel some discomfort from the exercise sessions, and as such the researcher will ensure that all participants fully understand the procedures involved and the level of discomfort they may feel. Participants will be excluded from the study if they demonstrate any contraindications on the initial PAR-Q.

During collection of saliva samples full safety procedures will be adhered to, including the use of protective gloves, and the provision and use of clean and sterile equipment. All samples and contaminated material will be disposed of in the relevant biohazard bins.

The use of ultrasound should not pose any risks. In a review by Salvesen and Lees (2009) the authors noted the extraordinary safety record of ultrasound, having no proven harmful effects in almost forty years of use in obstetrics. Ultrasound has very little risk since it does not involve radiation and participants will experience no pain from the procedure (Mulholland and Rolland, 2012).

Heavy load resistance exercise such as that completed in the 1RM protocol may pose injury risks to participants, although exact procedures outlined by ACSM (2010) will be followed to minimise these risks. This will also include the use of a squat rack with safety side bars, and the presence of two ‘spotters’ to assist the lifter should they get into difficulty. Delayed Onset Muscle Soreness may be experienced in the days following the procedure, although the effects are transient and should subside within 72 hours.

5. Can participants change their mind and withdraw from the project?

Individuals may withdraw from participation in the project at any time and without any disadvantage of any kind.

6. What information will be collected, and how will it be used?

Data from the testing procedures described in Section 3 will be collected and used to investigate the influence of somatotype on the various parameters and further establish the reliability of the measures used. This data will be stored securely in a lockable filing cabinet in the Department of Sport and Exercise. Only the Project Supervisor and Investigator will have access to the data. All data will be anonymous and destroyed after a period of five years.

The results of this project may be published, but the information will not be linked to any specific person. A copy of all your personal information, including results, supplement type and dosage will be given to you after completion of testing.

8. What if participants have any questions?

If you have any questions about the project please feel free to contact either:

The Investigators

Alex Crane

Research Assistant

Email: A.Crane.11@unimail.winchester.ac.uk

The Project Supervisor

Prof Simon Jobson

Professor in Sport & Exercise Physiology

Email: Simon.Jobson@winchester.ac.uk

Telephone: 01962 827516

Malika Felton

Sport Science Laboratory Technician

Email: Malika. Felton@winchester.ac.uk

Helen Ryan-Stewart

Senior Lecturer in Sport & Exercise Physiology

Email: Helen.Ryan@winchester.ac.uk

Telephone: 01962 827112

Appendix 2c: Consent form for reliability and non-trained comparisons (Chapters 4 and 5)

Participant's Consent

I _____consent to take in part in the research study titled:

Comparisons of muscle structure and salivary hormone responses to acute strength training between participants of different somatotype.

The investigator has explained the full details and parameters of all tests and procedures to me, and I have read the Information Sheet. I confirm that I have understood what participation will involve, and confirm that I have been made aware of all the potential benefits and risks of participation.

I declare that I have completed and signed the accompanying Physical Activity Readiness Questionnaire truthfully to the best of my knowledge, and that I have never been advised to abstain from any form of exercise by a medical practitioner. I know of no reason why participation in these testing procedures might present a risk to my safety.

I understand that any medical information that I have submitted will be treated as highly confidential.

I would like to be provided with a copy of the following for my personal records *(please tick)*:

Information Sheet ☐

Consent Form ☐

PAR-Q

Signature _____ **Date _____**

Witness _____ **Date _____**

Appendix 3a: Ethics approval letter for training study (Chapter 6)

THE UNIVERSITY OF WINCHESTER

Thursday 4th January 2018

Helen Ryan-Stewart

PhD Candidate

Department of Sport and Exercise

Faculty of BLS

University of Winchester,

Hants, SO22 4NR

Dear Helen Ryan-Stewart,

Re: Faculty of Business, Law and Sport RKE Ethics Application [BLS/18/01]

Title: *The influence of somatotype on adaptations to resistance training in untrained males.*

Thank you for your submission to the University of Winchester, Faculty of Business Law a rt (BLS) ethics panel.

On behalf of the Faculty of BLS RKE Ethics Committee I am pleased to advise you that the ethics of your application have been approved. Approval is for five years and is for the documentation submitted for review on 13/12/17. If the project has not been completed within five years from the date of this letter, re-approval must be requested.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Head of the Faculty BLS ethics committee.

Yours sincerely

Professor Maria Burke

Professor Maria Burke

Head of Faculty Research and Knowledge Exchange (RKE)

University of Winchester

Dr James Faulkner, Head of Ethics in the Faculty of BLS
Email: James.Faulkner@winchester.ac.uk; Tel: +44 (0)1962 624932

Appendix 3b: Information sheet for training study (Chapter 6)

Participants' Information Sheet, Consent Form and PAR-Q

Title of the Study: *The influence of somatotype on adaptations to resistance training in untrained males.*

Thank you for expressing an interest in this study. Please read the following information sheet ***carefully*** before deciding whether or not to participate in the study. If you choose to participate in the study, we thank you. As a participant, prior to taking part in any testing, you will be required to:

1. Carefully read this ***Information Sheet*** which will outline the procedures and the potential risks to yourself;
2. Complete and sign a ***Consent Form****;* and
3. Complete and sign a ***Physical Activity Readiness Questionnaire (PAR-Q)***

The Consent Form and the PAR-Q can be found at the end of this document.

If you do not decide to participate in the study there will be no disadvantage to you of any kind and we thank you for considering our request.

1. What are the aims of the study?

The aim of the present study is to investigate the effects of physique as measured by somatotype on adaptations to resistance training in those who are untrained from a resistance perspective.

2. What type of participants does the study require?

The present study hopes to recruit an approximate total of 30 male participants who have not had experience of 2 or more resistance training sessions in the past 6 months. Participants will take part in initial screening to determine whether they meet the physique requirements (mesomorphic – predominance of musculo-skeletal robustness or ectomorphic – linear and slender physique).

3. What will the participants be asked to do?

Individuals who volunteer to participate in the present study will be asked to attend an initial screening test to determine their physique. This will involve measurement of surface anthropometry; stature, body mass, 8 skinfolds (bicep, triceps, subscapular, iliac crest, supraspinale, abdominal, front thigh and medial calf), 3 girths (upper arm, mid thigh and calf) and 2 bone breadths (biepicondylar humerus and femur). At this stage if participants do not meet the physique criteria of the study, they will be supplied with a copy of their results but will be eliminated from further testing.

Those with established dominance will be assigned to a 16 week cross over training programme with a 4 week wash-out after 8 weeks. During one 8 week period they will either complete a novice strength training programme or continue with their normal activity regime, crossing over after 12 weeks (8 weeks training plus 4 week wash-out). Baseline measures will be taken of muscle thickness at bicep, triceps, hamstring and quad using ultrasound imaging, 10 repetition maximum for the programme prescribed exercises, and muscle activation during 10 repetition maximum testing using EMG. Further, baseline haemodynamics will be measured using NIRS, alongside haemodynamics during the 10 repetition for exercises involving selected muscle groups.

After completion of baseline testing, participants will begin their respective 8 week training period. All participants will be assigned personalised programmes based on their baseline or post 4-week wash-out 10 repetition maximums and will commence at beginner level due to their novice status. The programme will involve a whole body resistance programme using free weights and consisting of 4 sets of 8-12 repetitions, progressing gradually across the prescribed period. This will be completed during 3 supervised sessions per week with 48 hours rest in between. Baseline measuring protocols will be repeated at week 4, and post the final training session in week 8 or 9. All

participants in the strength training group will swap over to the no exercise group for the final 8 weeks and vice versa with the no training to the strength group.

All participants will supply both a training and food diary for the duration of the training programme.

4. What are the potential risks and discomforts of the study?

Due to the novice training status of the participants, it is likely that some delayed-onset muscle soreness (DOMS) will result from initial training sessions. Although uncomfortable, this is part of the natural training process, and should begin to ease after a few days. The severity of this DOMS will also reduce as the training programme progresses.

The novice status of the participants also requires some significant attention to be paid at the beginning of the programme to adopting correct technique. This will be further checked through supervised sessions throughout the programme to reduce injury risk to participants.

5. Other general health and safety considerations

Supervised sessions will result in a first aider being present throughout. The progression of the programme is in keeping with recommendations from ACSM (2002) and so is appropriately prescribed to avoid injury or over-training.

6. Can participants change their mind and withdraw from the study?

Individuals may withdraw from participation in the study at any time and without any disadvantage of any kind.

7. What information will be collected and how will it be used?

Data from the testing procedures described in Section 3 will be collected and used to assess if there is an influence of physique on the responses to resistance training in untrained participants. This data will be stored securely in a lockable filing cabinet in the Department of Sport, Exercise and Health. Only the Study Supervisor and Investigators will have access to the data.

The results of this study may be published, but the information will not be linked to any specific person. A copy of all your personal information, including results, supplement type and dosage (where appropriate) will be given to you after completion of testing, upon request.

8. What if participants have any questions?

In order to participate in the study please contact one of the following people:

If you have any questions about the study please feel free to contact either:

Primary Investigator

Helen Ryan-Stewart

Senior Lecturer in Sport and Exercise Physiology

Email: Helen.ryan@winchester.ac.uk

The Study Supervisor

Professor Simon Jobson

Professor in Sport and Exercise Physiology

Email:Simon.Jobson@winchester.ac.uk

Appendix 3c: Consent form for training study (Chapter 6)

Participant's Consent

I _____ consent to take part in this research study titled:

The influence of somatotype on adaptations to resistance training in untrained males.

The investigator has explained the full details and parameters of all tests and procedures to me, and/or I have read the Information Sheet. I confirm that I have understood what participation will involve, and confirm that I have been made aware of all the potential benefits and risks of participation.

I declare that I have completed and signed the accompanying Physical Activity Readiness Questionnaire truthfully to the best of my knowledge, and that I have never been advised to abstain from any form of exercise by a medical practitioner. I know of no reason why participation in these testing procedures might present a risk to my safety.

I understand that any medical information that I have submitted will be treated as highly confidential.

I would like to be provided with a copy of the following for my personal records *(please tick)*:

Information Sheet	☐
Consent Form	☐
PAR-Q	☐

Signed: _____*(Participant)* **Date:_____**

Signed: _____*(Witness)* **Date:_____**

Table 8.X: Non normal distribution data sets

Baseline Control	Baseline Training	Post Control	Post Training
Mesomorph: CRAG, BS BF Concentric and Eccentric PAm, CGBP BB Concentric PAm, BC TB Eccentric PAm, CGBP BB Eccentric TTP, BS RF ΔtHb, ΔO2Hb and HHb, CGBP TB ΔtHb, CGBP BB and TB ΔO2Hb, BC BB ΔO2Hb, BC TB ΔTSI Ectomorph: BC 10 RM, CGBP BB Concentric and Eccentric PAm, CGBP BB Eccentric TTP, BC BB Concentric TTP, BS BF ΔTSI, CGBP BB ΔtHb, BC BB ΔtHb, CGBP BB and TB ΔO2Hb, CGBP BB and TB ΔHHb, BC TB ΔHHb, BC TB ΔTSI	Mesomorph: CGBP 10RM, BC 10 RM, BS BF Eccentric PAm, BC BB Concentric and Eccentric TTP, BS BF ΔTSI, CGBP BB and TB ΔtHb, BC BB ΔtHb, CGBP BB and TB ΔO2Hb, BC TB ΔO2Hb, BC TB ΔHHb, CGBP BB and TB ΔTSI, BC TB ΔTSI Ectomorph: RF MT, CRAG, BS BF Concentric PAm, CGBP BB Concentric and Eccentric PAm, CGBP TB Concentric PAm, BC BB Concentric PAm, BC TB Eccentric PAm, CGBP TB Eccentric TTP, BC BB Concentric and Eccentric TTP, BS RF ΔtHb and ΔO2Hb, BS BF ΔTSI, CGBP TB ΔTSI	Mesomorph: BS BF Concentric and Eccentric PAm, CGBP TB Eccentric PAm, BC TB Eccentric PAm, CGBP TB Concentric TTP, BS RF and BF ΔtHb, BS RF and BF ΔTSI, CGBP BB and TB ΔtHb, CGBP BB and TB ΔO2Hb, BC TB ΔO2Hb, CGBP TB ΔHHb, BC TB ΔHHb, BC TB ΔTSI Ectomorph: RF MT, BS BF Eccentric PAm, CGBP TB Concentric PAm, BC BB Concentric PAm, BC TB Eccentric PAm, BS RF and BF Concentric TTP, CGBP TB Eccentric TTP, BC BB Concentric and Eccentric TTP, BS BF ΔO2Hb, CGBP BB ΔtHb, CGBP BB ΔO2Hb, BC TB ΔO2Hb	Mesomorph: TB, BF and RF MT, BS BF Eccentric PAm, CGBP BB Concentric PAm, BC BB Concentric TTP, BS RF and BF ΔtHb, BS RF ΔO2Hb, ΔHHb and ΔTSI, CGBP BB ΔtHb, CGBP BB and TB ΔO2Hb, BC TB ΔO2Hb, BC BB and TB ΔHHb, CGBP BB and TB ΔTSI, BC BB and TB ΔTSI Ectomorph: BS BF Eccentric PAm, CGBP BB Concentric and Eccentric PAm, CGBP TB Eccentric PAm, BC BB Concentric PAm, BC TB Eccentric PAm, BC BB Concentric TTP, BS RF and BF ΔtHb, BS RF and BF ΔO2Hb, BC TB ΔtHb, CGBP BB and TB ΔO2Hb, CGBP TB ΔHHb, BC BB ΔHHb