DOCTOR OF PHILOSOPHY

Understanding the Holistic Development of Elite Performance in Olympic Weightlifting: A Machine Learning Approach

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Award date:
2020

Awarding institution:
Bangor University

Understanding the Holistic Development of Elite Performance in Olympic Weightlifting: A Machine Learning Approach

PRIFYSGOL
BANGOR
UNIVERSITY

Ph.D. Thesis

by

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Thesis submitted to Bangor University in fulfilment of the requirements for the degree of Doctor of Philosophy at the School of Sport Health and Exercise Sciences

Yr wyf drwy hyn yn datgan mai canlyniad fy ymchwil fy hun yw'r thesis hwn, ac eithrio lle nodir yn wahanol. Caiff ffynonellau eraill eu cydnabod gan droednodiadau yn rhoi cyfeiriadau eglur. Nid yw sylwedd y gwaith hwn wedi cael ei dderbyn o'r blaen ar gyfer unrhyw radd, ac nid yw'n cael ei gyflwyno ar yr un pryd mewn ymgeisiaeth am unrhyw radd oni bai ei fod, fel y cytunwyd gan y Brifysgol, am gymwysterau deuol cymeradwy.

I hereby declare that this thesis is the results of my own investigations, except where otherwise stated. All other sources are acknowledged by bibliographic references. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree unless, as agreed by the University, for approved dual awards.

Dedication

These past four years have not come without the hardship and pain of loss of loved ones, all of whom have touched and inspired me to carry on in the most difficult of times. To my once student and dear friend Alexander Paul, my cousin Rachelle Ludgrove, step grandfather David Grant, uncle Steve Plunkett, and most recently my father, Adam Michael Buckmaster. It is with a heavy heart that I dedicate this thesis to you. Your memory will live on in all of the work I will continue to do.

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Acknowledgements

I am greatly fortunate to be in the position I am currently with the support of the many of people who have made it possible. It is at the very least that I give my acknowledgements to you below:

Nuria: It certainly would not have been possible to have get here without the support of my partner, Nuria. A case could certainly be made for co-authorship of this thesis! Thank you for being such a rock of support throughout the past 6 years. Nuria was the one to encouraged me to take the giant leap of faith and pursue a PhD and has sacrificed some of her professional endeavours to be here with me throughout our time in Bangor. Here's to the next chapter in our pursuit of happiness.

Family: To all my family who have shown us unconditional support over the years. To my mother Maxine, my sister Tia, my stepfather Michael and my grandfather Ronald, thank you for all of your guidance and encouragement in helping us through these four years; and no matter how hard we may try, we can honestly say that there is no place like home for a nice 'rice n peas' style sunday roast! Also thank you to the Villarino-Nieto family, who have been truly welcoming to me into their home in Valencia and have been a source of respite and reprieve for us over the summer months. It does of course go without saying that Valencia is indeed the home of the paella!

Friends: For all of the Facetime and WhatsApp conversations and exchange of endless banter and humour, you have contributed to this work in more ways you can imagine. Special acknowledgements are in order to Gareth, Kieron, Sam, Parris, Harry, Bradlee, Gregory and Etienne, who have always kept me in touch with my south east London working class roots.

Vicky: For all of the off the record office discussions and quick meetings at the gym and bus stop, it is safe to say Vicky's office has always remained open to me throughout my time here. Vicky has always kept the project in check by ensuring my wild appetite for creative approaches was kept grounded in the conventional. Vicky has praised my good work when it was deserved and has been gracious in her occasional 'time out' coach talks. I am proud to have to have been your first official PhD student. I'm also sure it is safe to say there would be no more surprises for you from here on in.

Gavin: Gavin has seen me through 7 years of academia since my time as an undergraduate student, 11 years ago. Gavin has always given me confidence and self-belief in my approach to my work and has inspired me to be creative in many ways. At times it has felt as though the world's problems were solvable in some of the meetings with Gavin. Here's also to the endless cultural discussions about music, cinema, and culinaria chief!

Simon Roach: Simon has been a great source of insight and knowledge in the sport of weightlifting. He has always been truly welcoming for me and for the project, especially at his weightlifting club, SAW. I have been in awe of the culture of dedication and belief he has created there. A true linchpin for the sport of weightlifting in Wales, it is no surprise that Simon has helped to put the governing body for Welsh weightlifting in the position is currently is today.

Weightlifting Wales staff, parents and athletes: The staff at weightlifting wales have always offered themselves immensely to the commitment of the project. To all of the hours, usually across evenings and weekends, of painstaking testing that have led us here. The culture around the organisation has been outstanding. Thank you especially to Neil, Christie, Luke, Ray, Justin, Hannah, Ania, and Calum, who have been integral to the project. Also thank you to the parents and the athletes who have selflessly committed to the cause of the project.

Lew: From studying catastrophe theory in a sports psychology module whilst at college, to having the Lew himself as the chair of this thesis committee. It can safely be said that it was an honour to have Lew oversee the progression on this project. Lew helped to inspire my thought to tap into areas that

were inconceivable four years ago. Thank you for the frank and brute honesty in keeping our ‘ducks in a row’ at all times on the project.

PhD Colleagues: To all the PhD colleagues who have been part of the SSHES way of life, and to all of my colleagues outside of the school who have offered refreshing perspectives on the life as a postgraduate student. Thank you for providing the endless stream of collaborative engagement as well as all the opportunities for *deliberate play* throughout my time here. To Robin, Dan, Ben, Seamus, Emily, Elle, and Eduardo, and all the rest of the SSHES team, may the force, or the vodka, be with you.

Thesis Abstract

This thesis aimed to extend the existing body of research that has deployed machine learning to conduct multidimensional investigations of expertise development (e.g. Güllich et al., 2019; Jones et al., 2019); and was the first to provide a detailed account of the pathway to elite performance in Olympic weightlifting. The thesis contains seven chapters, four of which are empirical studies.

Chapter 1 critically reviews current literature on expertise development and talent identification research. The review discusses research contributing the to the following talent development themes: (1) demographics and family sport participation, (2) physiological and (3) psychosocial characteristics, (4) sport participation history, and (5) sport specific practice activities. Empirical limitations of the current literature are also discussed which are centred around the need for research to accurately capture the dynamic nature of expertise development; as well as for sport specific frameworks of talent development to incorporate the relative importance of the developmental themes discussed.

Chapter 2 presents a study that examined the degree with which future performance could be accurately represented from historic performance data. Advanced data handling and machine learning techniques were used to both prospectively and retrospectively examine the pathway to elite senior performance at each competitive age group classification. Predictive models were able to correctly classify elite performance at each stage in the pathway with 79-92% accuracy. The earliest age from which performance could be accurately predicted gave rise to the discussion of specialization in weightlifting as a developmental theme. Evidence for the role of NGB's in effectively enabling talented athletes to transition between stages in the pathway were also discussed (Sotiriadou, Shilbury, & Quick, 2008).

Chapter 3 investigated the discriminatory features in the biographical development of current and past senior weightlifting athletes. Semi-structured interviews reported the

demographics, sporting history, competitive milestones, and weightlifting specific practice activities in sixteen weightlifting athletes. Logical attributes provided a detailed description of the discriminatory features of performance in each developmental theme. Qualitative accounts of the athlete's experiences at competitive milestones also detailed the athlete's transition throughout the competitive pathway. The final predictive model classified the groups with 85% classification accuracy.

Chapter 4 presents a multidisciplinary observation of the development of youth and junior weightlifting athletes. The holistic profiles of 29 junior weightlifting athletes were observed longitudinally over a 10-month period. This holistic profile captured the developmental themes discussed in chapter 1. Odds ratio calculations uncovered both common and discriminating features in the profiles of high performing relative to low performing athletes, from which empirically derived logical statements could inform the description of high-performance attainment. A summary predictive model successfully differentiated the groups with 91% accuracy.

In a three-part investigation, Chapter 5 comprehensively examines the prevalence of the relative age effect at the highest level of representation in weightlifting. The historic performance data from all youth, junior, and senior Olympic, world, commonwealth and continental championships was examined in order to determine the influence of the relative age effect and subsequent medal attainment. The findings provide evidence for an interactive influence of bodyweight category classification and relative age on subsequent medallist status. This chapter also explored the psychosocial characteristics that likely emerge as a result of the relative age effect.

In chapter 6, the theoretical implications of the current thesis are discussed, the need for future research to continue to explore the dynamic development of expertise with state-of-the-art analytics are also emphasised.

Chapter 1

General Introduction

General Introduction

The development of high performance in sport is a dynamic and holistic process, operating as a complex interplay of a multitude of features (Fransen & Güllich, 2019; Johnston, Wattie, Schorer, & Baker, 2018). A considerable body of theoretical frameworks, along with supporting evidence, have illuminated the construct over the past 30 years (e.g. Balyi, 2001; Bloom, 1985; Côté & Vierimaa, 2014). Moreover, these frameworks have adopted increasingly holistic perspectives of talent development. In a recently published position stand commissioned by UK sport, the quality of existing evidence from a broad range of factors influencing the attainment of elite sports performance were explored and recommendations for policy makers and practitioners were outlined (Rees et al., 2016). These recommendations centred around the characteristics of the performer, including physiological and psychosocial factors, as well as the environment that the performer was exposed to in their early formative years. Moreover, whilst proposing avenues for future research, Rees and colleagues invited research to embrace the complexity and multidisciplinary nature of talent development. This chapter will therefore review the existing evidence for the wide-ranging influences of talent development to date. In accordance with the themes discussed by Rees et al., (2016), evidence will be reviewed in this chapter that relate to the following five sections: (1) demographics and family sport participation, (2) physiological and (3) psychosocial characteristics, (4) sport participation history, (5) competitive milestones in the sport, and (6) sport specific practice activities. A visual depiction for these themes, along with their subcomponents, are presented in figure 1.

Demographics and familial sport participation:

Familial sport participation:

Parental experience in sport

Sibling experience in sport

Same sex older sibling

Homeplace throughout development:

Population size and density of homeplace throughout early (6-12 years), middle (13-15 years), and later (16-19 years) of development

Schooling:

Attendance of sport school throughout early (6-12 years), middle (13-15 years), and later (16-19 years) of development

Relative age:

Month of birth in calendar year

Birth quarter

Sport history and weightlifting specific involvement:

Sport involvement throughout early (6-12 years), middle (13-15 years), and later (16-19 years) of development

Weightlifting specific and related involvement

Number of competitions per year and time spent in competition

Hours involved in weightlifting specific (technical) and related (flexibility/mobility) training

Themes of elite performance development

Psychosocial characteristics:

Personality:

Big five personality characteristics

Perfectionism

Obsessiveness

Ruthlessness

Athlete behaviours and attitudes to training and competition:

Achievement motivation

Commitment to training

Relative importance of sport

Passion for sport

Competitive milestones in weightlifting:

Highest level of domestic and international representation

Key pathway performance indicators

Technical and psychological challenge in pathway

Physiological characteristics:

Body composition

Anthropometrics

Maximum dynamic strength

Stretch shortening cycle utilization

Mobility/trunk stability

Microstructure of practice activities:

Within athlete:

Deliberate play vs practice
Focus of attention
Mental skills training

Practice structure:

Whole versus part practice
Specificity of practice
Constant versus varied practice

External influences:

Conveying of information
Vicarious experiences
Prescriptive versus constraints coaching

Sources of feedback

Figure 1. A multidimensional model of the themes of elite performance development

1.1 Demographics and family sport participation

1.1.1 Family sport participation

The influence of the family on child sport participation has been extensively reported in the literature (Bloom, 1985; Côté, 1999; Fredricks & Eccles, 2005; see Horn & Horn, 2012 for a review). Based on the theoretical frameworks of the bioecological model of human development (Bronfenbrenner, 1993; Bronfenbrenner & Morris, 1998) and the expectancy value model (Eccles, 2005; Eccles, Wigfield, & Schiefele, 1998), parental values and belief systems are proposed to influence the motivation and choice behaviours in subsequent achievement contexts (e.g. academic achievement, music or sport). As such, parental involvement in sport, although equivocal in some findings (e.g., Brustad, 1993, 1996; Dempsey, Kimiecik, & Horn, 2016; Kimiecik & Horn, 1998; Welk, Wood, & Morss, 2003) has generally been shown to be associated with the child's subsequent participation in sport (Fredricks & Eccles, 2005; Stevenson, 1990; Xiao Lin Yang, Telama, & Laakso, 1996), particularly in elite level athletes (Stevenson, 1990).

For instance, when asked to recall accounts of early involvement in their sport, most of the 29 elite athletes interviewed by Stevenson (1990) highlighted occurrences of accompanying their parent to a game in which the parents themselves were involved, or being taken along to enroll into a sport by a parent. Similarly, Xiao Lin and colleagues (1996) surveyed 1881 Finnish school children and found that children's participation in physical activity was significantly associated with their fathers' level of physical activity. Moreover, when followed up three years later, children who were persistently more active in their sport were more likely to have a father who was actively involved in sport than those that dropped out from sport participation altogether.

A similar notion can also be applied to sibling sport participation (e.g. Côté, 1999b; Duncan, Duncan, Strycker, & Chaumeton, 2004; Hardy et al., 2017; Hopwood, Farrow,

MacMahon, & Baker, 2015; Stuart, 2003), in which often older siblings are reported to directly influence an athlete's sport participation and subsequent achievement status (i.e. elite; Hopwood et al., 2015). Specifically, in the findings reported by Hopwood and colleagues (2015), the siblings of elite athletes had also attained pre-elite or elite status in their respective sports, whilst the siblings of non-elite athletes also tended to be non-elite. Additionally, and interestingly, Hopwood et al also revealed that birth order appeared to be an important indicator of subsequent achievement status. Elite athletes in their study tended to be second or later born, which would suggest that later born siblings are exposed to conditions best suited to elite performance attainment. The authors had discussed these findings in the context of motor development, which was supported by prior investigations revealing that later born children demonstrated better motor coordination than first born or only born children (Krombholz, 2006).

Another potential explanation for this birth order effect could be the exposure to rivalries with their older sibling from a younger age. As reported by Hardy and colleagues (2017) serial gold medalling athletes tended to exhibit rivalries in the form of sport with their, often same sex and older, sibling. This constant drive to outperform their older sibling in sport could have fostered both the motivational and motor adaptations which could have promoted subsequent elite performance attainment.

1.1.2 Homeplace throughout development

A wider contextual factor that has been shown to influence expertise attainment is the population size and density of the homeplace town (e.g., Bruner, Macdonald, Pickett, & Côté, 2011; Côté, Macdonald, Baker, & Abernethy, 2006; MacDonald, Cheung, Cote, & Abernethy, 2009), particularly in the athletes formative years (Allen & Dunman, 2010). Towns with smaller population sizes (50, 000 – 100, 000 inhabitants) tend to have an over representation of elite athletes relative to towns with larger populations (>500, 000; e.g. Côté

et al., 2006). Additionally, athletes from towns with very small populations (<1000) tended to be underrepresented. One potential mechanism for this finding was that towns with too small a population size do not have the infrastructure to accommodate for the sports facilities that would enable the development of sporting talent (Curtis & Birch, 1987). Conversely, towns or cities with very large populations tend to have a smaller ratio of facilities available per person, which could also mean scarcity of resources in terms of coaching time as well as facility availability. This would therefore suggest an almost inverted-U like relationship that would best describe the most optimal population size for the development of elite sports performance. Hancock and Côté (2014) have also discussed some of the sociological mechanisms that have accounted for this effect. In line with the notion that towns with optimal population sizes offer a better ratio of sports facilities available per inhabitant, which in turn allows for more affordances for skill development, the authors proposed that these towns tend to elicit less security concerns for parents whilst children are free to engage in sporting related activities in their local community. Additionally, the provision of competitive opportunities at the grass-root level tends to be more localised, and thus offer more opportunities for athletes and sports teams to compete against each other more regularly, which would in turn promote a stronger network of social support from family members and the wider community. This stronger social support would provide the athletes with a stronger sense of self concept and identity around their sport, which may lead to more invested effort into the development of performance. Hancock and Côté (2014) termed this the big fish little pond effect, which reflects the stronger sense of self identity that talented individuals from smaller homeplace communities may have compared to similarly profiled athletes from larger cities.

More recently, population density has been reported to be a more accurate reflection of the home place effect than population size (Rossing, Nielsen, Elbe, & Karbing, 2016),

thereby suggesting that a greater number of inhabitants per unit area may provide a better indication of town infrastructure and subsequent opportunities for skill development than absolute town size (Hancock, Coutinho, Côté, & Mesquita, 2018; MacDonald et al., 2009; Rossing et al., 2016). Other factors, such as lower local crime rates and positive social norms that have also been strongly linked with population density may also provide a wider contextual backdrop for the mechanisms underpinning the homeplace effect (Dempsey, Brown, & Bramley, 2012; Lawson, 2009).

In addition, proximity to talent clubs and sports facilities have also been investigated as contributors to the home place effect (Rossing, Stentoft, Flattum, Côté, & Karbing, 2018a). Specifically, Rossing et al. (2018) reported that communities in Denmark that were in closer proximity to talent clubs had a proportionately higher representation of elite athletes than communities that were further away. Similarly, proximity to sports facilities was shown to be associated with NHL player development in 4 out of the 6 Canadian provincial regions recently studied (Farah, Schorer, Baker, & Wattie, 2018). Rossing and colleagues proposed that this closer proximity exhibits less fiscal challenge on families in terms of travel. Additionally, developing athletes in communities closer to talent clubs tend to adopt more of a sporting culture and senses of pride about achievement in sport, whilst also having more accessibility to current and past senior athletes as role models for developing athletes. These local communities may also be more likely to receive funding from local authorities and incentives for talent development (Chase & DiSanti, 2017), which could ultimately result in better facilities and more access to higher quality coaching.

1.1.3 Relative age effect

An overrepresentation of relatively older athletes have been widely reported in athlete populations (e.g. Helsen, Van Winckel, & Williams, 2005; Jones, Lawrence, & Hardy, 2018;

Vaeyens, Philippaerts, & Malina, 2005). Widely referred to as the relative age effect, this effect describes the biased selection of relatively older individuals onto talent selection programmes whose birthdates are normally close the start to the cut off dates for an age group. This selection is usually on the basis of biological maturity, and as such may often conceal true talent potential in relatively younger athletes (Malina et al., 2005; see Cobley, Mckenna, Baker, & Wattie, 2009, for a review). For instance, Malina et al. (2005) demonstrated that age, size, maturity and experience level accounted for a very small proportion of variance in skill level (10 to 19%), which suggests that skill may be better explained by a variety of other factors in addition to physical maturity. These proportions, however, may not be accurately reflected in the decisions of coaches when selecting relatively older athletes on to talent programmes.

Hancock and Cote (2013) proposed a theoretical framework for the underlying psychosocial mechanisms of the relative age effect. This framework centred around the advantages that relatively older athletes inherit, as well as the self-fulfilling prophecies that are reinforced through coach-athlete and parent-athlete interactions. Specifically, the authors describe the advantage that relatively older athletes inherit when they are enrolled onto sports programmes by their parents from a relatively younger age. For example, Delorme et al (2010) reported that proportionately more athletes whose birthdates were in the first quarter of the calendar year were more likely to be enrolled onto soccer programs at the under 7 age group than those born later in the calendar year, which would essentially expose the athletes to coaching for a longer period of time. Hancock, Adler, and Côté (2013) termed such an advantage as the Matthew effect, which denotes the biblical reference to the notion that those that inherit advantages benefit from these advantages in both the short and long term, or in other words, “the rich get richer and the poorer get poorer” (p. 631). In relation to the self-fulfilling prophecies, Hancock, Adler, and Côté (2013) also referenced both the Pygmalion

and Galatea effects, which refer to the positive effects that placing high expectations on relatively older athletes has on their subsequent achievement (i.e. the Pygmalion effect), which would also in turn influence the positive self-concept that the relatively older athletes have of themselves (i.e. the Galatea effect).

Whilst the proposed benefits of being relatively older in the pathway are clearly evident, the influences of the relative age effect on the development of relatively younger athletes are not as well understood, although some observational evidence suggest they may undergo much tougher developmental experiences (McCarthy & Collins, 2014). In addition to showing reduced rates of enrolment onto sport to begin with, evidence has also supported an increased dropout of these relatively younger athletes (Delorme, Boiché, & Raspaud, 2010). The authors largely attributed these findings to the differences in physical maturity which disadvantage relatively younger athletes, particularly as differences in the dropout rates were lowest in the under 7 age group where differences in physical maturity are less pronounced compared with older age groups (Delorme & Raspaud, 2009). However, whilst there are clearly many challenges imposed on the development of relatively younger athletes, the longer-term implications of these challenges could be of potential benefit to those who remain in the sport. This notion becomes even more apparent when considering that the relative age effect does not necessarily transfer to the senior elite level (Cobley, Baker, Wattie, & McKenna, 2009; McCarthy, Collins, & Court, 2016a). Recent evidence has also supported this notion, as an over representation athletes born in the fourth quarter at the super elite level has been observed (Jones et al., 2018). Future research should endeavor to explore this further, perhaps by revealing some of the underpinning psychosocial mechanisms of this potential long term quarter 4 advantage.

1.2 Anthropometrics and physiological factors

One of the fundamental tenets of the nature-nurture debate of expertise attainment is the relative importance of genetic predisposition versus biological adaptation through consistent training (see Tucker & Collins, 2012, for a review). This is particularly apparent within the development of sporting expertise in which large variability exists in the volume of deliberate practice required to attain elite athlete status (i.e. some athletes attaining elite status in just 3000 hours of practice, whilst others acquired significantly more, e.g. Kraus et al., 2001; Morss et al., 2004), which raises the contention that individual differences owing to genetic factors may be contributing to this variability. This is further supported by a recent meta-analysis which has found that deliberate practice accounts for just 20% of the variance in expertise attainment (Macnamara, Hambrick, & Oswald, 2014).

A theoretical model proposed by Tucker and Collins (2012) outlines the potential combined effects of innate characteristics with the effects of training for the attainment of elite performance. The authors proposed that innate ability is represented as the upper and lower limits of performance potential, whilst exposure to training enables the upper limits of innate ability to be achieved. Innate characteristics, such as sex, are largely determined by genetic factors, but most characteristics, such as height, $V0_2$max and skeletal muscle strength are determined by the combined effects of genetic and environmental factors (Ross Tucker & Collins, 2012). Of particular interest to the current thesis is skeletal muscle strength and anaerobic power in which a large variability attributable to hereditary factors have been reported (~15 - 90% and 46 – 84%, for strength and power respectively; Stewart & Rittweger, 2006). More recent investigations have also uncovered some specific genetic profiles that have been linked to anaerobic adaptions to resistance training. Specifically, the angiotensin-converting enzyme (ACE) and alpha-actinin-3 (ACTN3) genes have both been associated with performance in power dominant sports such as sprinting (e.g., Chan et al.,

2008; Macarthur et al., 2008; Yang et al., 2003). Caution should however be expressed when interpreting the study of specific genes and athletic performance, as these studies are predominantly limited to observational findings and as such evidence from a truly randomised controlled experiment would be very difficult to perform.

Additionally, one would also expect a large influence of anthropometrical characteristics to promote the optimum biomechanical efficiency for the execution of weightlifting related motor programmes, another factor which one would expect to have a large hereditary component (cf. Tucker & Collins, 2012). This would suggest that the potential for attaining high level weightlifting performance would ultimately be attributable to biological factors that would largely be underpinned by genetics.

Whilst this may appear to be a theoretically sound basis for profiling performance for the purposes of talent identification, difficulties may arise in practice when determining the influence of maturation on these innate characteristics. Many of these genetically determined characteristics are notoriously unstable over time, particularly during periods of peak height velocity (Buchheit & Mendez-Villanueva, 2013). It is therefore generally recommended to factor maturation into any form of physiological profiling. Some investigations have attempted to incorporate classifications of biological maturation into respective talent development practices (see Cumming, Lloyd, Oliver, Eisenmann, & Malina, 2017, for a review). The work of Till and colleagues have also examined this topic extensively (Till, Cobley, O' Hara, Cooke, & Chapman, 2014; Till, Morris, Emmonds, Jones, & Cobley, 2018; Till & Jones, 2015). This includes the interpretation of performance tests according to maturation (Till et al., 2018); the longitudinal examination of maturation and its interaction with relative age over time during adolescence to differentially affect the development of anthropometric and fitness characteristics (Till et al., 2014); as well as the examination of the efficacy of different maturation groups (Till & Jones, 2015). Additionally, perhaps more

prospective longitudinal research, particularly when controlling for influences of adaptations than can be attributed to engagement in early non-organised or organised practice, may also warrant further investigation.

1.3 Psychosocial characteristics

Psychological and personality traits as determinants of elite performance attainment have been investigated for the best part of 30 years (e.g. Mahoney & Avener, 1977). It is evidently abundant in the literature that elite athletes possess much more motivation to engage in training and competition in their respective sports (e.g. Boes, Harung, Travis, & Pensgaard, 2014; Gould, Eklund, & Jackson, 1993; Jones, Hanton, & Connaughton, 2002). The characterisation of this motivation has been described from a range of perspectives. For instance, in line with the premise of self-determination theory, an athlete's motivation may be characterized as behaviour that is directed towards the attainment of some form of external reward, such as winning a gold medal at a championships, or toward the achievement of internally derived sources of motivation, such as the achievement of personal task mastery related outcomes (Deci & Ryan, 2000). More recently, achievement motivation has been characterized as the attainment of competence which is mainly governed by differences in effort perception in relation to task attainment (Cury, Elliot, Da Fonseca, & Moller, 2006). This has been broadly separated into two main constructs. The first is in relation to the achievement of competence that is based on an objective standard of reference. In this construct, termed mastery motivation, the achievement of competence at a task is perceived to be distinctly associated with the amount of effort invested into the task (Nicholls, 1984). Therefore, individuals high in task mastery perceive that the attainment of competence can be achieved with significant investment of effort and are thus motivated towards the attainment of mastery by investing their own effort resources. Conversely, individuals may perceive the

attainment of competence as being disassociated with the investment of effort, and as such may in turn perceive task competence to be inherently different amongst different individuals (Nicholls, 1984). This ego-oriented form of achievement motivation, termed performance motivation, thus manifests itself in behaviours that are directed towards the attainment of competence that are determined by a socially prescribed standard. Individuals high in this construct are more inclined to be motivated to outperform others (Roberts, Treasure, & Conroy, 2012). This form of achievement motivation may lead to some maladaptive achievement behaviours, particularly when the perception of one's own ability is low (Nicholls, 1984).

Conversely, the attainment of task mastery may lead to more adaptive forms of outcomes, such as increased intrinsic motivation (Elliot & Harackiewicz, 1996), positive evaluations of competence (Cury, Da Fonséca, Rufo, Peres, & Sarrazin, 2003), and absorption in the task (Cury, Elliot, Sarrazin, Da Fonseca, & Rufo, 2002). This form of mastery has also been shown to be positively associated with high performance attainment (Durand-Bush & Salmela, 2002; Vallerand et al., 2007a). Similarly, evidence for the both task and ego-oriented forms of achievement motivation on performance at the elite (Cervelló, Rosa, Calvo, Jiménez, & Iglesias, 2007) and super elite (Pensgaard & Roberts, 2003) levels have been documented.

These forms of motivation have also been strongly associated with harmonious and obsessive passion (Vallerand et al., 2008a), which both are both characterized as, at least at the behavioural level, a strong inclination towards engagement in an activity (Vallerand et al., 2003). This inclination is also proposed to be incorporated into the person's identity to the extent that they are perceived to be highly valued activities (Aron, Aron, & Smolan, 1992; Csikszentmihalyi et al., 1993). Harmonious and obsessive passions differ on the basis in which they are conceived and internalised into the individual's identity, which may not

necessarily be mutually exclusive. Harmonious passion refers to the automatic internalisation of an activity that is in agreement with one's core values and is one with which they can holistically identify themselves. Harmonious passion is internalised automatically as a result of this agreement. Conversely, obsessive passion refers to the internalisation that is not in complete agreement with one's core values or may occur as a result of an adoption of attitudes or beliefs of others. This form of internalisation therefore does not occur automatically and may need to be controlled by the individual in order to be internalised. Obsessive passion may therefore result in negative emotional outcomes as a result of this conflicting internalisation, whilst harmonious passion is proposed to foster positive affect and healthy persistence in the activity (Vallerand et al., 2003). Both forms of passion have been reported to be higher in expert musicians (Mageau et al., 2009; experiment 3), as well as being positively associated with deliberate practice in high school basketball players, which in turn was positively associated with performance (Vallerand et al., 2008a).

In addition to some of the psychological characteristics outlined above, personality characteristics have also recently been examined in the context of sports performance attainment. More specifically, personality characteristics such as conscientiousness (Piedmont, Hill, & Blanco, 1999; Woodman, Zourbanos, Hardy, Beattie, & McQuillan, 2010), dispositional optimism (Grove & Heard, 1997), and adaptive perfectionism (Stoeber, Uphill, & Hotham, 2009; Stoll, Lau, & Stoeber, 2008) have been positively associated with sports performance. These findings support the notion that dispositional traits that ultimately form part of an individual's core characteristics may indeed be important prerequisites to elite performance attainment.

Rees et al. (2016) outlined the need for future research to include psychological and personality profiling as part of their investigations. This paper was subsequently supported by a psychosocial enquiry into the developmental experiences of both super-elite and elite

British athletes using in-depth semi structured interviews (Hardy et al., 2017). The authors reported that commonalities existed between the sample with regards to family values, conscientiousness, and commitment to training, whilst the sample differed with regards to their attitudes to training and competition (i.e., a motivation towards the attainment of both mastery and outcome factors, as well as an inherent need to succeed in their respective sports) and personality traits (i.e., adaptive perfectionism, obsessiveness, and ruthlessness and selfishness). These characteristics were likely manifested as a result of experiencing a negative foundational life event which was coupled with the positive experience of finding sport, as well as a career turning point which enhanced their motivation to achieve (Hardy et al., 2017).

1.4 Sport participation history and weightlifting specific involvement

Early diversification versus specialisation have been recognised as an important contributor to the development of sporting expertise. Whilst the exposure to extensive deliberate practice has been accepted to be a fundamental prerequisite to expertise attainment (Ericsson et al., 1993), significant motivational and effort resources would be required in order to sustain high volumes of deliberate practice which occurs particularly later in the athlete's career (Baker & Young, 2014; Soberlak & Côté, 2003). It is therefore proposed that early (i.e. between the age of 6-12 years) exposure to sport sampling and play through non-organized sporting activities would foster the necessary motivational characteristics for later deliberate practice attainment during the investment years (i.e. aged 15 years and above; Côté, Baker, & Abernethy, 2003, 2007).

However, as originally discussed in the developmental model of sports participation (DMSP; Côté, Baker, & Abernethy, 2003, 2007), the importance of early diversification and play may indeed depend on the specific demands of the main sport, as well as the age at

which peak performance is expected to be achieved. In gymnastics, for example, peak performance may occur as early as age 16 in women, and thus early engagement in high volumes of deliberate practice may be more necessary in order to promote the necessary adaptions for elite performance. Similarly, in most professional soccer academies, players are recruited from as early as 7 years of age, and as such are exposed to high quality organised practice from an early age. The evidence for late specialization as a discriminating characteristic of high performance has, however, gathered ground in recent years (Güllich, 2017, 2018; Moesch, Elbe, Hauge, & Wikman, 2011). Furthermore, theoretical propositions for the transfer of talented athletes who drop out of one sport into another sport has also been proposed in order to encourage those athletes to remain in the elite performance system (Vaeyens, Güllich, Warr, & Philippaerts, 2009). As well as fostering the motivational characteristics, evidence for late specialization has also emerged to support the potential learning benefits that may accrue from early organised practice in other sports (Güllich, 2017; Güllich, Kovar, Zart, & Reimann, 2017). For example, Güllich and colleagues (2017) investigated match play performance improvements in a sample of paired match junior soccer players. The authors demonstrated that although early multisport activities did not differentiate performance at baseline testing, it did differentiate performance at the end of the 2-year study period, thereby suggesting a delayed effect of early multisport involvement on subsequent performance. The authors had discussed these findings in the context of preparation for future learning (Bransford, Brown, & Cocking, 1999), which ultimately suggests that exposure to other sports offer the foundational learning experiences for transfer to later learning. Similar findings were observed in a multisport comparison between medallists and non-medallists (Güllich, 2017).

Additionally, early sport sampling would be suggested to foster the biological adaptations to training that would encourage later transfer into the specialist sport (Baker &

Young, 2014; Côté et al., 2007). In a weightlifting context, this would be expected to be sampling sports that would foster both the strength and flexibility adaptations that could be transferred into weightlifting performance. Moreover, exposure to sports such as gymnastics or sports with specific emphases on strength and conditioning, such as track and field athletics or rugby, could potentially be of benefit to subsequent weightlifting development.

1.5 Competitive milestones in sport

Whilst the demographics, formative experiences, physiological and psychological attributes are indeed important factors in the development of elite performance, the achievement of specific competitive milestones in the sport in question are arguably one of the most critical factors in demonstrating elite performance itself. Competitive milestones refers to the achievements attained along the pathway to elite performance, the refers to both the competitive experience at specific levels of the pathway (i.e., club, regional, national, international) as well as specific performances within these levels of representation (e.g., personal best performance at international junior levels). Recent multidimensional research has begun to profile the competitive milestones of elite athletes and have revealed specific milestones in which elite performances differ from their non-elite counterparts (Güllich et al., 2019; Jones et al., 2019). For example, Jones and colleagues (2019) found that the highest level of representation by 14 years of age, as well as the number of competitive overs bowled in cricket were amongst the critical features in the profile of elite English cricket spin bowlers. These recent findings support the contention that competitive milestones are important features in the development of elite performance, and thus should be included as part of the holistic profile of the athlete.

However, whist the competitive milestones are indeed important factors, they only tell a part of the story in terms of the effect they have on the performer. The level of challenge encountered at specific competitive milestones indeed allows for a deeper understanding of

the psycho-behavioural and coping skills the athlete may develop (Collins, MacNamara, & McCarthy, 2016). Evidence from the developmental profiles of elite level performers indeed suggests that challenge is a common feature in the pathway to elite performance (MacNamara, Button, & Collins, 2010). These findings have given rise to the proposition that regular challenge, or a 'rocky road', should be present in the optimal pathway to elite performance (Collins & MacNamara, 2012), and as such policy makers and practitioners should endeavour to optimise the talent development environment to appropriately periodise challenge the athlete, along with providing appropriate social support (Collins, MacNamara, & McCarthy, 2016).

1.6 Microstructure of practice in weightlifting

At the level of the athlete, it is broadly accepted that expertise is honed with extensive exposure to practice, as originally purported by Ericsson and colleagues in the theory of deliberate practice (Ericsson et al., 1993). Within sport, the volume of deliberate practice has been shown to differentiate elite from non-elite athletes across a variety of sports at the both the junior (Ward, Hodges, Williams, & Starkes, 2004; Weissensteiner, Abernethy, Farrow, & Müller, 2008) and senior level (Baker, Côté, & Deakin, 2005; Helsen, Starkes, & Hodges, 1998), with particular differences in deliberate practice volume occurring later in adolescence (i.e. during what the developmental model of sports participation DMSP would refer to as the 'investment' years; Côté et al., 2007).

However, inconsistencies regarding recommendations exist for the optimum amount of deliberate practice required to attain elite status (Rees et al., 2016). The so called 10,000 hour rule of thumb inherent within the deliberate practice theory was originally purported to emphasize the extensive volume of practice required to attain expertise in musicians (Ericsson et al., 1993), and as such would not be entirely applicable to sports performance (Rees et al., 2016). These recommendations for sports performance become further complex

when factoring in evidence demonstrating lower volumes of practice in super elite relative to elite athletes (Rossum, 2000). Moreover, in a recent case study in skeleton, just 14 weeks of what the authors termed ‘deliberate programming’ was sufficient in preparing a novice athlete, with no prior skeleton deliberate practice experience, for a world class event (Bullock et al., 2009). This would therefore lend support to the notion that deliberate practice volume, although important, may not be a fundamental component of optimising the pathway to attain elite sports performance, and perhaps more emphasis should be placed on the practice conditions that optimise skill learning. Whilst summarising their recommendations for practice volumes, Rees et al. (2016) highlighted that future research should include scrutiny of the intentions and specific practice activities performed.

A theoretical framework, termed the challenge point framework, was proposed by Guadagnoli & Lee (2004) which conceptualises the interaction of skill level and task difficulty in optimizing practice conditions. This framework proposes that practice conditions can be optimized by encouraging performers to engage in tasks in which difficulty is most functional to skill level (i.e., more difficult tasks for higher skill level), which would in turn promote the optimum amount of information available to the performer (usually in the form of augmented feedback). The authors proposed that conditions of task difficulty could operate as a function of contextual interference which occurs from combining random and blocked practice designs (e.g. Shea, Kohl, & Indermill, 1990; Magill & Hall, 1990). More pertinent to Olympic weightlifting, however, is that task difficulty could also be underpinned by whole versus part practice (see Fontana, Furtado, Mazzardo, & Gallagher, 2009 for a review), constraints versus prescriptive learning (Hardy, Mullen, & Jones, 1996; Masters, Poolton, Maxwell, & Raab, 2008; Newell, 1986), induced variability of practice (see Shapiro & Schmidt, 1982, for a review), and the specificity of practice hypothesis (Henry, 1968; Lawrence et al., 2014).

The following sections will aim to review the literature around many of the aforementioned practice activities, particularly the themes that are pertinent to the sport of weightlifting. In order to sufficiently contextualise these themes, they have been grouped into the following three higher order categories: (1) within-athlete activities, (2) external influences, and (3) practice structure. Each section, and their related themes, will be discussed briefly below.

1.6.1 Within-athlete activities

Activities that occur within the performer refers to the psycho-motor behaviours and/or strategies that the performers themselves deploy both during and outside of practice. This essentially includes (1) the motivational state of the performer towards practice (i.e., deliberate practice versus deliberate play) (2) the focus of attention adopted during practice, (3) the time spent outside of training developing mental skills.

1.6.1.1 Deliberate practice versus deliberate play

As previously discussed, deliberate practice refers to the intention of the performer to engage in practice activities specifically for the development of their own performance without the inherent need for enjoyment, whilst deliberate play refers to the engagement in a practice activity for the purpose of enjoyment. It is thus possible that the motivational state of the performer towards practice would therefore signify the intentions of the performer during practice, which may have implications in terms of the intention to engage in creative behaviour during practice (Bowers, Green, Hemme, & Chalip, 2014; Memmert, 2017).

1.6.1.2 Focus of attention

The performers attentional focus indeed refers to the performers locus of attention during the practice and execution of a practice activity, and has received widespread interest for developing the effectiveness and efficiency of a given motor programme (see Wulf, 2013 for a review). In general, attentional focus during the execution of a skill is primarily thought

to be either directed towards the sensations of the body (i.e., internally) or away from the physical sensation of the body (i.e., externally). Studies of attentional focus have shown widespread empirical support that externally derived forms of attentional focus is shown to optimise the consistency, reliability and accuracy of the movement (e.g. Wulf & Su, 2007; Wulf, Höß, & Prinz, 1998; Zachry, Wulf, Mercer, & Bezodis, 2005). Of particular interest to the development of elite performance, is the benefit that the adoption of an external focus as on the development of skill learning (Wulf, 2007). Moreover, the adoption of an external focus has been shown to speed up the learning process such that more efficient and effective movement patterns are achieved sooner (Wulf, 2007).

1.6.1.3 Mental skills training

Mental skills training refers to the cognitive somative techniques an individual in order to further enhance their control of their psychosomatic states (see Behncke, 2004 for a review). These mental skills include mental rehearsal, mental imagery, visualization, visuo-motor behaviour rehearsal, cognitive-behaviour therapy, biofeedback, progressive muscle relaxation and meditation. Metal skills training interventions in sport have resulted in reduced state anxiety (Ong & Griva, 2017), as well as a stronger awareness of emotional states in athletes (Baltzell, Caraballo, Chipman, & Hayden, 2014). Specifically in relation to mental rehearsal and imagery, early experimental evidence supports the notion that mental practice combined with physical practice produces superior learning and retention than physical practice alone (McBride & Rothstein, 1979), thereby highlighting the importance of mental skills training in the development of elite performance.

1.6.2 External influences

External influences refer to the externally derived influences on the athlete both in and around the practice environment. More specifically, these factors take the form of external agents which interact with the athlete in the performance environment. External

influences contain the following themes: (1) information conveyed to the learner, (2) sources of feedback, (3) prescriptive versus constraints-based coaching, and (4) vicarious experiences. Each will be discussed briefly below:

1.6.2.1 Information conveyed to the learner

The communication of information to the learner has received widespread attention in the motor control and learning literature. A key feature of this line of research is the optimal type of information that should be conveyed to the learner, particularly between verbal instruction and demonstrations (Williams & Hodges, 2005). Demonstrations, which are examined in the context of observational learning, are proposed to provide the learner with a visual template for a desired movement pattern (Hodges & Franks, 2002), and is the preferred method when the primary learning goal is the simple replication of a movement pattern (Williams & Hodges, 2005). Verbal instruction, however, is also deemed effected when encouraging the athlete to engage in the problem-solving process without relying on an available template or solution (Hodges & Franks, 2002). As highlighted by Williams & Hodges (2005), information conveyed may be differentially suited to the context, the skill to be learned, as well as the learner's skill level, thus implying that a combination of different types of information conveyed would be optimal in the development of elite performance. The optimal proportions of these information types, especially in combination with other forms of information, such as video feedback, certainly warrants further investigation.

1.6.2.2 Sources of feedback

Sources of feedback refers to the sources the athlete can derive information from and is thought to be derived from a coach or external agent, such as a video or display (i.e., externally), or directly from the athletes themselves (i.e., internally). Internally derived feedback sources enable athletes to develop an internal representation of the motor programme (van Vliet & Wulf, 2006), and usually stems from a combination of visual,

auditory, and proprioceptive sensory sources. This internal representation is proposed to enable the athlete to detect errors about their own performance, from which they can adjust their action plans accordingly. Extrinsic, or augmented feedback is usually provided as part of the coaching process to support the development of intrinsic feedback (van Vliet & Wulf, 2006). This form of feedback can take the form of knowledge of performance, or knowledge of results, the former of which would often take the form of technical feedback from a coach regarding the athletes movement execution (van Vliet & Wulf, 2006), whilst knowledge of results is normally given about the outcome of the specific movement attempt (i.e. success or failed; Schmidt & Lee, 1999; Gabriele Wulf, Shea, & Lewthwaite, 2010).

1.6.2.3 Vicarious experiences

Vicarious experiences describes the experience of learning through observation or acquiring experience through the experiences of others. Vicarious experiences are thought to be one of the four sources of self-efficacy, along with performance accomplishments, verbal persuasion, and psychological states (Bandura, 1986). Of interest to the development of elite performance, however, is the role that vicarious experiences has in regulating the observational learning of the athlete. Much like the early discussion on demonstrations, vicarious experiences, via watching other athletes performing, may provide a template for performance solutions which the athlete can aim to mirror in their own actions.

1.6.2.4 Constraints versus prescriptive coaching

Constraints versus prescriptive coaching refers to learning conditions that learners are placed under to arrive at performance solutions. Prescriptive coaching refers to the direct recommendation of performance solutions to the learner. This is normally in the form of verbal cues or instructions which provides explicit information about the execution of a motor task. Conversely, constraints based coaching is based on the deliberate manipulation (either from the coach or the athlete) of either the task, individual, or performer, in order to

encourage the performer to arrive at their own performance solution (Renshaw, Chow, Davids, & Hammond, 2010). Constraints based coaching is based on ecological psychology and dynamical systems theory (Araújo, Davids, & Hristovski, 2006; Vilar, Araújo, Davids, & Button, 2012), and would be akin to an implicit learning paradigm which refers to the learning of tacit knowledge without intention, after which it becomes difficult to verbalise once learned (see Patterson, Pierce, Bell, & Klein, 2010, for a review).

Whilst prescriptive coaching is commonplace in most sports, many experimental investigations in the sport psychology literature have raised questions over its effectiveness for sports performance (Beilock & Carr, 2001; Hardy et al., 1996; Masters et al., 2008). For instance, in a simple golf putting task, Hardy and colleagues (1996) demonstrated that explicit instruction, synonymous to prescriptive coaching, led participants to consciously control their movements under conditions of anxiety, which ultimately led to detrimental performance. Conversely, participants under conditions of implicit learning, demonstrated performance improvements under anxiety. The authors concluded that implicit learning did not provide learners the explicit basis from which to reinvest under anxiety, and therefore would not constrain what would otherwise be a natural movement (Masters, 1992).

1.6.3 Practice structure

Practice structure concerns the organisation of practice activities within the practice environment of the athlete. Practice structure will be discussed in relation to the following themes: (1) whole versus part practice, (2) specificity of practice, (3) induced variability of practice.

1.6.3.1 Whole versus part practice

The acquisition of a motor skill can indeed be a complex process, particularly as the skill to be learned may vary in degrees of spatial and temporal complexity. The decision to simplify a skill by practicing it as separate distinct parts, therefore, may facilitate in the motor

learning process (Magill, 2007; Schmidt & Wrisberg, 2008). This decision, of course, does depend on the task complexity and level of organisation required between phases of movement (Naylor & Briggs, 1963). Tasks with high complexity and low organisation are proposed to be better practiced as parts. Conversely, tasks low in complexity but require a high level of organisation between movement phases are better learned when practiced as a whole movement. Part practice may also be more beneficial for complex serial tasks (Schmidt & Wrisberg, 2008; Fontana, Furtado, Mazzardo, & Gallagher, 2009).

However, to our knowledge, empirically derived recommendations for discrete motor tasks that are both highly complex and highly organised, such as that found in Olympic weightlifting (e.g., the practice of complex movements under high load that require very little margin for error), currently does not exist in the research literature. Based on the recommendations provided above, however, one could speculate by suggesting a combination of both part and whole practice may be optimal for these tasks. This would also be supported by the anecdotal observations of weightlifting specific technical training programmes. Future research should endeavour to support this contention.

1.6.3.2 Specificity of practice

Specificity of practice refers to the similarity with which the conditions of practice match that of competition. Early accounts of the specificity of practice principle asserted that the demands of practice should aim to be as specific to practice as possible (Henry, 1968). Moreover, practice conditions that closely meet the demands of competition are proposed to encourage the optimization of available sensory information which is likely to be encountered during competition, even to the extent that transfer to different competition conditions disregards this sensory store, which in turn disrupts performance (Elliott, Pollock, Lyons, &

Chua, 1995; Khan & Franks, 2000; Khan, Franks, & Goodman, 1998; Mackrous & Proteau, 2007).

Perhaps very pertinent to the sport of weightlifting in particular, is the notion that practice with anxiety leads to more robust performance under pressure in competition (Lawrence et al., 2014; Oudejans, 2008; Oudejans & Pijpers, 2009). For instance, Lawrence and colleagues (2014) demonstrated, using both a simple golf putting task (experiment 1) and a rock-climbing task (experiment 2), that practice with anxiety lead to no decrements in performance in the anxiety transfer test, whilst practice without anxiety did. Of particular interest was the observations that (1) performance in the anxiety test was highest in the group that were exposed anxiety practice in the second half of their acquisition phase, suggesting that practicing with anxiety closer to competition may optimise the specificity effect, and (2) performance was lowest in the low-anxiety test in groups that practiced with anxiety, which implies that practice with anxiety is only beneficial for transfer to competitions which are likely to induce anxiety.

1.6.3.2 Induced variability of practice

Variability in movement execution is indeed a part of the normal random variation in the control of motor actions. The extent with which variation in movement execution can be induced whilst maintaining the same outcome has been shown to be a functional characteristic of skilled individuals (Arutyunyan, Gurfinkel, & Mirskii, 1969; Bernstein, 1967). These early accounts have contributed to the hypothesis that deliberate movement variability may indeed be a necessary characteristic for optimal performance (Harbourne & Stergiou, 2009; Ranganathan & Newell, 2013).

Most of the theoretical rationale for this hypothesis stems from the concepts from ecological psychology (Gibson, 1979), and dynamical systems theory (Kelso, 1995; Phillips,

Davids, Renshaw, & Portus, 2010) which conceptualises the regulation of human behaviour as a complex interaction between the performer with their environment (see Seifert, Komar, Araújo, & Davids, 2016, for a review), and one in which the performers motor system can flexibly adapt to environmental perturbations to achieve perceptual-motor stability and thus allows for reproducible emergent behaviours (Van Emmerik & Van Wegen, 2000).

2. Limitations of the current research and thesis rationale

It is thus clear that a body of research has indeed comprehensively explored the wide-ranging influences on talent and expertise development, which has without question contributed to the development of the elite athletes over the past 20 years. However, whilst the theoretical backdrop may indeed provide a sound foundation from which to build, problems may present themselves when attempting to consolidate this body of information in a manner that captures the dynamic and fluid nature of real-world application. It is in this real-world application, such as that of the sports practitioner, where the underlying assumptions from which much of the evidence is based may be violated, or where a proposed effect may be free to be confounded by random error. The biological maturity associated with the relative age effect, for instance, may apply to two of the five players on the soccer team born in the first quarter, but who still may be significantly smaller than the player born in the third quarter whose father was a basketball player. Moreover, without a dynamic contextual framework, the sports practitioner may find it difficult to apply much of this information holistically, and as such much of its valuable implications may fall to the wayside in the day-to-day operations at the coalface of performance development.

Additionally, the evidence for these theoretical influences have predominantly used linear estimations of relationships such as regressions and comparisons of group means. Whilst these methods allow relationships to be intuitively interpreted within the context of

the study, many of these estimations are fundamentally based on the best representation over the course of a hypothetical ‘long term’, which make observations about the day-to-day variations in the short term very difficult. One could argue these forms of linear estimations would be best suited to epidemiological research, in which larger scaled trends are observed within an entire cohort or population.

A recent argument in the social sciences as an alternative to linear estimations would be to adopt a Bayesian estimation approach (Kruschke, Aguinis, & Joo, 2012). Put simply, Bayesian estimation refers to a method of deriving at expectations about an uncertain event that is based on the occurrence of another event at an earlier point in time (see Zyphur & Oswald, 2015, for a useful guide). A Bayesian approach would therefore derive at expectations of the real world that is based on an “if–then” application of logic. This application of logic would perhaps be better suited to the dynamic framework discussed above, and more broadly to the study of expertise development (Ackerman, 2014).

However, this solution should only solve a part of the problem. The next challenge lies in choosing the appropriate prior information from which to base these real-world expectations, especially when resource constraints, such as time, may be limited. In other words, how does one decide to prioritise deliberate practice volume over psychological development? Or vice versa? This also links directly with an additional limitation of the current research literature. Specifically, most investigations have explored these talent development themes in relative degrees of isolation, and thus the relative importance of these influences on the holistic development of talent remains to be completely understood. In the advent of machine learning algorithms and advanced data handling procedures, however, it is now possible to begin exploring important relationships by deploying algorithms that explore the relative importance of a multitude of features simultaneously. The selection of the critical features can then be determined from this analysis. Moreover, the accuracy with which this

critical subset best represents a particular problem can also be assessed, which enables for the assessment of a ‘model’s’ performance in real world expectations.

The current thesis will therefore aim to utilize and deploy machine learning techniques and advanced data handling procedures to advance the understanding of expertise development. This thesis will aim to build on the already existing body of research that have used similar methodologies (Güllich et al., 2019; Jones et al., 2019) but will aim to comprehensively explore the development of expertise specifically in Olympic weightlifting. Secondary aims of the research programme include: (1) to deploy machine learning and advanced data processing to perform a pathway analysis of all historic weightlifting competition performance data in Britain, and (2) the explore the interactive effects of the relative age effect and bodyweight classification on medal attainment at the highest level of international representation. The research programme was designed in collaboration with talent pathway management from the welsh national governing body for weightlifting, and also formed part of a national talent identification and selection programme. The research will aim to explore some of the critical features in the developmental biographies of current and past senior weightlifting athletes using a retrospective recall paradigm that are centred around each of the five sections discussed above. This study will uniquely deploy classification algorithms developed from all historic competition performance data to determine two distinct performance groups within the sample (i.e., elite and non-elite). Additionally, advanced data manipulation and coding will establish empirically derived logical statements, which are assessed through odds ratio estimations, to provide a detailed description of the discriminative characteristics in the biographical development of the performance groups. The research will then explore the application of these logical attributes on the development of junior athletes using a prospective longitudinal research design.

3. Thesis structure

The thesis is presented as a series of research articles in chapters 2 to 4, each of which will build on findings from its preceding investigation. Chapter 5 is presented as a standalone research article. The supplementary information for studies in chapters 2 through to 4 are presented in the appendices.

1. Chapter 2 presents a study that examined the degree with which future performance could be accurately represented from historic performance data.
2. In order to build on the findings from chapter 2 in determining the holistic profile of high-performance attainment, chapter 3 investigated the discriminatory features in the biographical development of current and past senior weightlifting athletes. Semi-structured interviews reported the demographics, sporting history, competitive milestones, and weightlifting specific practice activities in sixteen weightlifting athletes.
3. With the aim of validating the findings from chapter 3 in a prospective research design, chapter 4 presents a multidisciplinary investigation of the development of youth and junior weightlifting athletes. Chapter 4 also extends the theorical framework of chapter 3 by including physiological and psychosocial athlete profiling.
4. In a three-part investigation, Chapter 5 comprehensively examines the prevalence of the relative age effect at the highest level of representation in weightlifting.
5. Chapter 6 discusses the theoretical implications of the current thesis, and the need for future research to continue to explore the dynamic development of expertise with state-of-the-art analytics are also emphasized.

Chapter 2

A state-of-the-art analysis of the British performance pathway in Olympic weightlifting

Abstract

The ability to determine future performance from its current state lies at the heart of talent identification. However, difficulty often arises when attempting to predict elite performance accurately. The current study aimed to investigate the extent with which the pathway to elite performance in weightlifting can be accurately represented with advanced data handling and machine learning techniques. Historic competition performance data from British weightlifting athletes was examined both by (a) comparing the performance and competitive history profiles of elite senior athletes with that of their non-senior counterparts at each age group along the pathway, and (b) by comparing the discriminatory features in the performance and competitive history profiles of athletes at each age group in the pathway. Odds ratio estimations of logical attributes provided a detailed description of both the Women's and Men's elite performance pathway at u13, u15, u17, u20, and u23 age groups. Predictive modelling demonstrated that the pathway to elite performance could be classified with a 79-92% accuracy rate. The findings demonstrate that elite performance can be effectively predicted from historic performance. The themes of specialization and athlete transitioning are also discussed.

KEYWORDS: talent identification; Olympic weightlifting; pathway analysis; machine learning

1. Introduction

Increasing results driven measures of success in elite sports has led to the growing need for talent identification systems to operate efficiently in identifying and developing sporting potential (de Bosscher, 2015). More investment from NGB's into talent identification systems have generally led to more comprehensive athlete monitoring procedures, and incentives for talented athletes to remain in the performance pathway from as early and for as long as possible are increasingly commonplace in elite sports (de Bosscher, 2015). Consequently, research into talent identification has gathered ground, particularly over the past decade (see Johnston, Wattie, Schorer, & Baker, 2018, for a review). Researchers have now begun to adopt more holistic profiling of elite sports performance for the purposes of both talent identification and development (e.g. Güllich et al., 2019; Jones et al., 2019). At the very core of talent identification, though, lies the need to accurately associate future performance with that of its current state, and to create the pathway that effectively optimises that connection.

The national governing body for weightlifting in Britain, like that of many cgs sports (measured in centimetres, grams or seconds), typically adopts a performance funnel approach to many performance pathway procedures. Athletes are usually selected onto high performance programmes based on their expected performance attainment for the next competitive cycle. This is usually represented as a mathematical formula which estimates typical performance parameters across time (i.e., the combined maximum snatch and the clean & jerk) from as early as 4 years prior to a target competition, which is usually the Olympic or commonwealth senior games. This formula is then used to estimate an ideal progression of performance to potentially achieve a medal at the target competition (see Chiu, 2009 for an example). Whilst this approach may serve to provide an objective basis for performance, adopting such an outcome-oriented approach has been a contentious topic

amongst sport psychologists and talent development researchers (Elferink-Gemser, Jordet, Coelho-E-Silva, & Visscher, 2011; Johnston et al., 2018). For instance, Hill and colleagues (2010) have shown that socially prescribed perfectionism, which could occur as a result of outcome-oriented athlete monitoring, has been shown to be a precursor to avoidant coping and burnout in junior athletes (Hill, Hall, & Appleton, 2010). Additionally, this approach to talent identification does not take into account the holistic nature of performance development and as such any talent identification procedures that are solely based on performance related criteria may lead to the overestimation of future potential in early high achievers (Abbott, Button, Pepping, & Collins, 2005; Howe, Davidson, & Sloboda, 1998).

However, whilst the holistic profile of the athlete should not be overlooked, talent identification through intuitive methods, such as the observation of current sports performance, is that which, in essence, characterizes talent identification. Moreover, the ability to observe sports performance in its current form is part of what drives many elite sports coaches and practitioners to develop prospects into high achieving athletes. This intuitive form of talent identification should therefore be preserved in elite performance environments. Furthermore, high performing athletes should also be appropriately motivated and rewarded, whilst the potential for late development should also be properly safeguarded.

This approach would therefore present the need to accurately inform the assessment of current performance on the basis of the likelihood of future elite sports performance. If current performance is going to determine the outcome of future performance, then it should be provided in a context that is its most accurate possible reflection of future performance potential. In the advent of machine learning and sophisticated data handling procedures, one can begin to map the performance of current athletes with that of past athletes who have achieved similar performances. The fate of these past athletes can begin to inform the likelihood of future elite performance attainment that is based on the profile of the current

athlete. The predictive accuracy of this ‘model’ can be fine-tuned with higher volumes of past data, which ultimately leads to more accurate estimations of future elite performance attainment. The aim of this study is to therefore provide an analytical framework from which the likelihood of future performance can be accurately represented, whilst also preserving the intuitive approach to talent identification.

This study will combine a bottom-up and a top-down approach to analysing the pathway to elite performance in British weightlifting. The top-down approach will involve observing the historical performance data from a sample of already established elite senior athletes at earlier stages in their developmental pathway. Additionally, the historical data of athletes who have not attained elite performance at the senior age group will serve as a comparator to the elite sample. The top-down analysis thus allows for a retrospective examination of the data, from which discriminatory features of performance can be extracted that could ultimately provide a premise for an ideal pathway to long term elite sports performance at the senior level. Additionally, the bottom-up approach will observe separate samples of athlete performance data at each stage in the developmental pathway and will aim to correlate current athlete performance with their respective developmental outcomes (i.e., elite performance attainment) at later stages in the pathway. The bottom-up analysis allows for a more prospective approach to the problem by determining the developmental outcomes in the following age group that are best associated with current performance. In other words, the bottom-up analysis should provide an ideal pathway to elite sports performance over a shorter period.

One study that has used a similar approach to that outlined in the current study (Brouwers et al 2012). Using data from three separate tennis organisations, the study deployed a top-down and bottom-up approach to investigate the extent with which senior performance was associated with junior performance from as early as u14. They found that

early performance was associated with performance later in the pathway, although this was not the only means of elite performance attainment. The current study will aim to extend the methodology to pathway analyses used by Brouwers and colleagues by providing a detailed description of each stage in the developmental pathway. As well as providing performance data, this detailed description will also aim to provide information about the amount of competitive experience acquired at each stage in the pathway. In addition, the likelihood of future elite performance on the basis of current performance, through means of an odds ratio estimate, will also be incorporated into the analysis. This should aim to provide practitioners with an informative method for quantifying the value of current sports performance.

2. Method

2.1 British weightlifting competition data

All available competition data from the British weightlifting national governing organization's website (www.britishweightlifting.org) was downloaded, formatted, and saved to a spreadsheet for further analysis. This dataset included all youth, junior, senior and open competitions from 1st January 2001 to the 19th January 2019. In addition, all international competition data in which any British athlete had competed between in 2001 and 2019 (representing either great Britain or their respective home nation), was downloaded from either the international weightlifting federation's (www.iwf.com/competition-results) or European weightlifting federations website (https://www.ewfed.com). Each competition entry consisted of the following information: (1) the name and date of the competition (including the age group classification), (2) the name and date birth of each athlete competing in each competition, (3) the bodyweight classification group and the athletes recorded bodyweight (4) the load for each snatch and clean & jerk attempts, as well as successful and unsuccessful outcome (5) the final recorded snatch and clean & jerk, as well as the total combined weight, and (6) the final rank positions for each athlete in the competition. This rank position was

based on the total combined weight lifted within each weight category. So that each athlete in the dataset could be tracked chronologically by age, any athlete for which date of births were not listed at any point in the dataset were removed from the data. This resulted in the data containing a total of 9,236 observations of competition entries from a total of 2,010 athletes.

2.2 Top-down pathway sample

As previously mentioned, the top-down analysis involved comparisons in the developmental pathways of elite senior versus non-elite senior athletes. In order to establish an elite sample of senior athletes in the data, any athlete was classified as elite if they had recorded three or more competition totals (which is the combined maximum loads for the snatch lift and the clean & jerk lift) that fell into the top 80 percent of all historic British competitive performances at one or more of the following senior competitions: [i] a British senior championships, [ii] a continental senior championships, [iii] a world senior championships [iv] a commonwealth senior games or championships, or [vi] an Olympic senior games. These competitions were selected as the highest level of representation for British weightlifting athletes in the senior age group. So that the athletes analysed in the top-down analysis were assured to be older than 23 (i.e., the age at which senior status would technically be determined) whilst achieving these performances, and so that they could be traced back to as early as the u13 age group in the dataset, the dataset was filtered so that only athletes who were born after the 1st January 1990 and before the 31st December 1996 were retained.

Additionally, in order to establish a comparative group, a non-elite group was established by classifying any athletes in the dataset born in the same time period and those who performed in the same competitions previously outlined but did not record 3 or more totals above the 80th British percentile. This resulted in a total of 23 athletes (11 females, 12

male) who were classified as elite, and 81 athletes (41 females, 40 male) who were classified as non-elite.

All athletes in the data were traced back to their earliest appearance in the competition data. For each competition, athletes age at competition was calculated by dividing the difference in days between the athlete's date of birth and the competition date by 365.25 (which reflects the number of days in a calendar year, factoring in a leap year). The competition data for each athlete was then grouped by the following age groups: u13, u15, u17, u20, and u23. Due to the limited sample size for female athletes in the u13 age group, however, the pathway analyses for women started from the u15 age group in both the top down and bottom-up analyses.

2.3 Bottom-up pathway sample

In order to investigate the prospective relationships in the data, and to compliment the findings in the top-down analysis by preserving the number of total athletes in the sample, a bottom-up analysis was performed in parallel with the top-down analysis. For the bottom-up analysis, the dataset was partitioned into distinct age groups based on the internationally recognised competitive age groups starting from the u13 age group (u13, u15, u17, u20, u23 and senior). This formed distinct samples for both female and male athletes at each age group. Each athlete in each sample grouping was then tracked longitudinally and classified into either elite or non-elite based on whether they subsequently achieved a total that fell into the top 80th percentile or above in any competition in the succeeding age group sample (e.g., performances at u15 were used to classify the u13 sample). In other words, athletes were classified based on their later performances in the higher age group. This prospective approach enabled the assessment of the athlete's current performance as a predictor of their future performance. Any athlete who dropped out of the dataset before the next age group were classified as non-elite, as they did not attain a total greater than the 80th percentile in the

age group above. Figure 2 provides a schematic overview of the top-down and bottom-up pathway analyses.

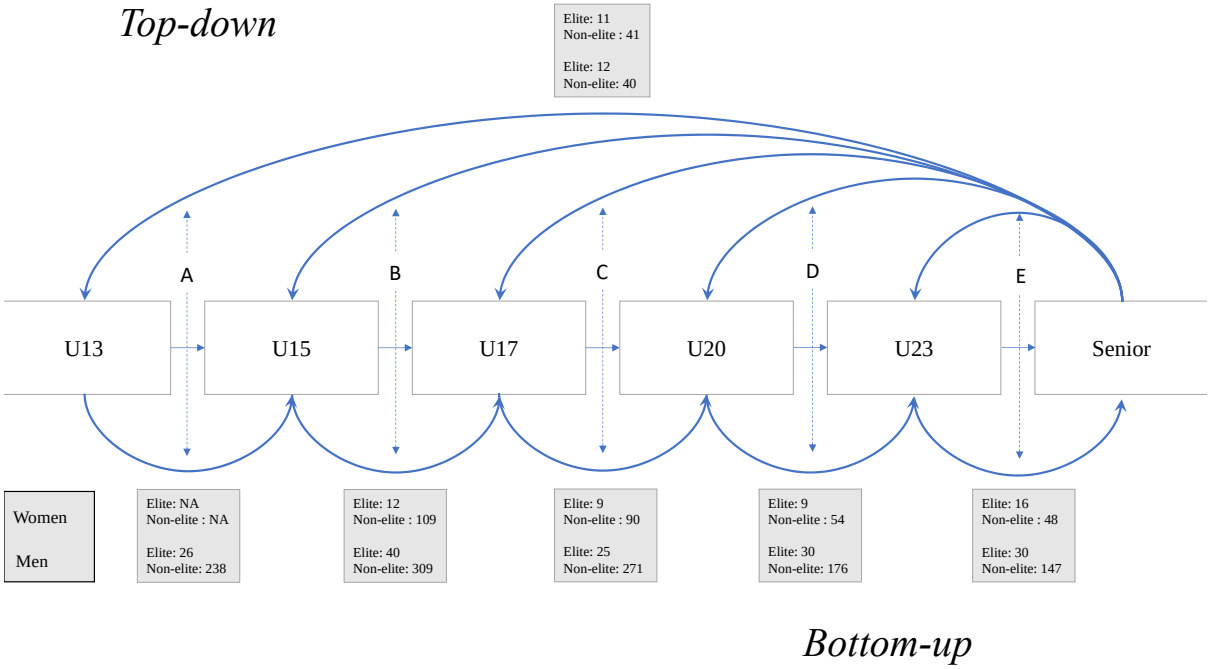

Figure 2. A schematic representation of the organization of the top-down and bottom-up pathway analyses. Note: The curved blue arrows represent the organisation of the pathway at each analysis. Dashed arrows A-E represent the separate analyses performed in parallel at each age group.

2.4 Variable extraction

The competition data for both top-down and bottom-up analyses were group by age group, and summary statistics were computed for each athlete at each age group. The summary statistics were categorized into three distinct sub-categories: (1) competitive performances, (2) weight selection in competition, and (3) competitive history profiles. Each section will be explained briefly below:

2.4.1 Competitive performances:

The mean residual combined total was computed as a measure of competition performance for each athlete in that age window. In order to control for variances in age, body mass, and competitive experience, expected competitive performances for each observation was predicted from a population norm formula, and the differences between the predicted and actual values were used in the analysis. The formulas were generated by non-linear regressions on the full dataset with bodyweight, age and estimated competitive experience (calculated as the difference between the age at each respective competition from the age the athlete first appeared in the data) as predictors of the total combined weight lifted in competition (see appendices for model coefficients and hypothesis tests). These formulas factored in cubic relationships between all three predictors and the total combined weight. These relationships are independently depicted in figure 3. Any athlete in the dataset whose competition performance was greater than that predicted would be considered to be performing above the respective population norm for their respective age and bodyweight. The opposite would be the case for any athlete whose personal best fell below their respective predicted value.

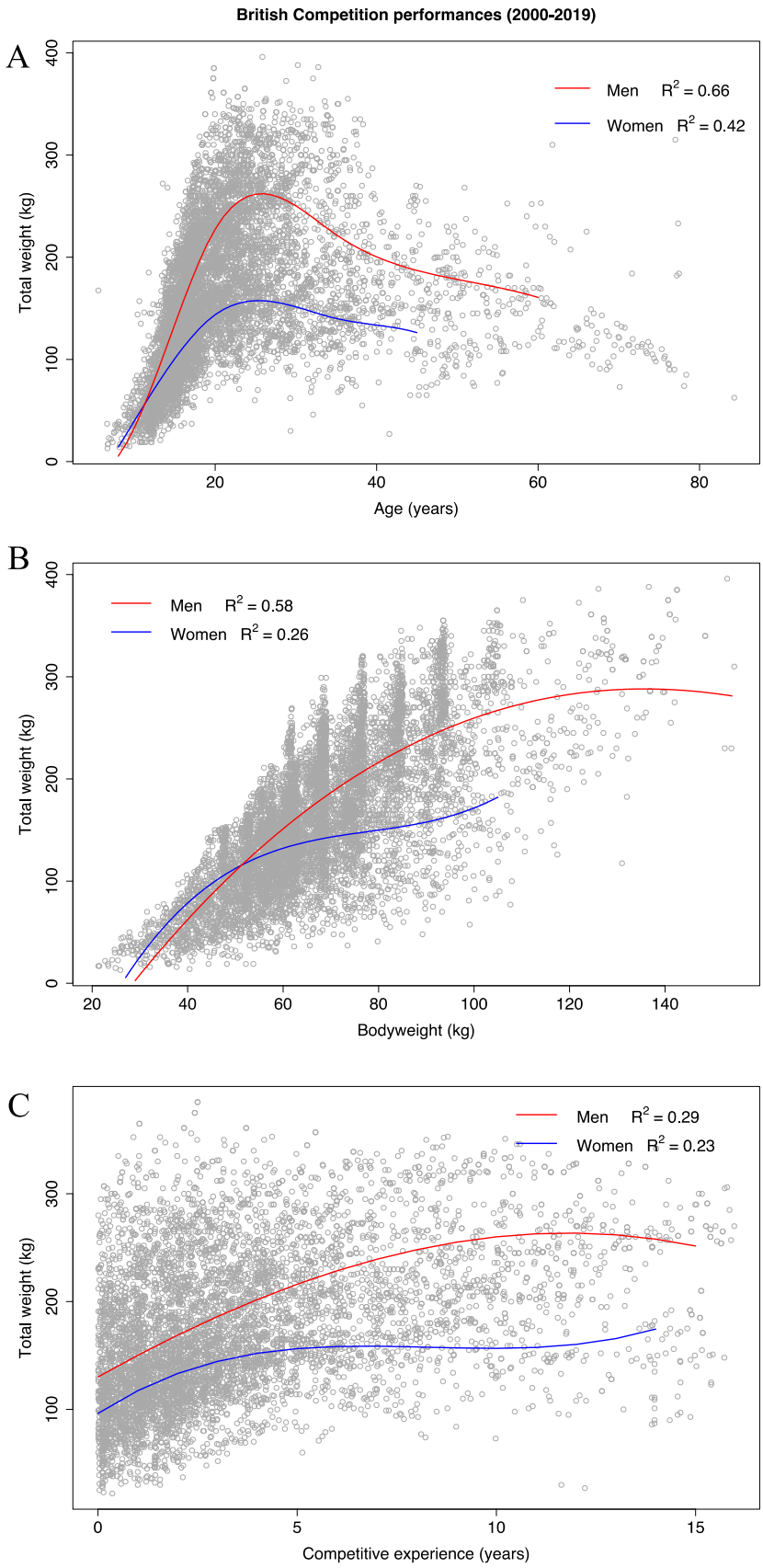
British Competition performances (2000-2019)
A
Men R2 = 0.66
Women R2 = 0.42
Total weight (kg)
Age (years)
B
Men R2 = 0.58
Women R2 = 0.26
Total weight (kg)
Bodyweight (kg)
C
Men R2 = 0.29
Women R2 = 0.23
Total weight (kg)
Competitive experience (years)

Figure 3. A depiction of the independent relationships between (A) age, (B) bodyweight, and (C) competitive experience and competition performance. As can be seen in figure 3A, the relationship between bodyweight and lift load is best represented as a curved line with three distinct curvature points, which suggests a sharp increase in load prior to 20 years of age, with peak performance normally occurring at around 25 years of age, followed by steady decline with age from 30 onwards. Figures 3B and 3C are represented as a plateaued increase in competition performance with bodyweight and competitive experience.

2.4.2 Weight selection in competition

Weight selection in competition was used to account for the competitive behaviour of each athlete in competition. Each weightlifting competition is structured such that each athlete has three possible attempts at each lift, starting with three attempts for the snatch, followed by a short interval, then followed by three attempts of the clean and jerk. The selected load for the opening attempt of each lift is usually lighter than the athletes expected maximum in order to place a minimum worthwhile score on the competition scoresheet, whilst putting enough tactical pressure on other athletes to also achieve their opening attempt. Providing the opening attempt is successfully completed, it is common to increase in loads for the second and third attempts that are closer to the athletes expected maximum. Higher increases in load for second and third attempts may also allow for athletes to be placed later in the waiting cue for their attempt, which could ultimately increase their rest time between attempts. This would incentivise athletes to select larger opening attempts than their opponents that would place them behind a rival athlete in the waiting cue. As the loads for each attempt, as well as their respective outcomes (i.e., success or failure), are recorded on each competition scoresheet, three possible aspects of competition behaviour for each lift were of potential importance, and thus were included in the pathway analyses: (1) the average

opening attempt of each lift at each age group, (2) the average load increase for the second attempt of each lift, and (3) the average load increase for the third attempt of each lift.

In order to control for the influence of age and bodyweight, loads for each first attempt of each lift were compared against predicted values that were based on age, bodyweight, and competitive experience. The formulas used to predict these values were formulated using the same method as that for the previous section, such that successful first attempt loads for the snatch and clean & jerk in the entire dataset were regressed on to age, bodyweight and competitive experience (see appendices for model coefficients, and for a breakdown of the expected load attempts). Separate regressions were also performed on the load increase for each attempt of each lift using age and bodyweight as predictors (the population norms for load increase are also displayed in the appendices). This allowed for all athletes in the dataset to be compared against a population norm on all six weight selection attributes. The mean residual scores were thus calculated for each age window and were put forward to the next stage in the analysis.

2.4.3 Competitive history profile

As well as the specific performance related parameters described above, each athlete in the data was profiled based on the competitive experience they had acquired throughout each age group window. The profile included (1) an estimate of cumulative competitive experience (which was estimated from the difference between the maximum age of the athlete in each respective age group and the minimum age of the athlete in the dataset overall), (2) the total number of competitions competed in each age group window, and (3) the number of times competed in each competition at each level of the pathway.

Each competition in the dataset was classified according to the competition level and age group along the pathway. A schematic representation of the competition pathway for

weightlifting in Britain is shown in figure 4. As figure 4 depicts, the competitive pathway is formed of several levels which are separated into domestic (i.e., local/developmental, regional, home nation, and British) and international (i.e., developmental, continental, commonwealth, World and Olympic) events. Each competitive level is further separated into age group classifications which denotes the upper age limits for participation eligibility. These age group classifications are youth, which denotes any age group up to and including the u17 age category (i.e., u11, u13, u15, u17), junior, which denotes the u20 and u23 age groups, followed by senior competitions, in which athletes above 23 years typically compete. Lower age group limit eligibility for any youth events start from age 13 from the 1st January of the respective year, whilst the lower age limit for any junior or senior events is age 15. As such, an athlete who is 15 years of age can be eligible to compete in both a senior and a youth competition for that calendar year. Open and university age groups typically do not have an explicit age limit, although attendance at a university is required to participate in any university event. Each competition in the dataset was classified into one of 40 possible competition types (8 competitive levels x 5 age groups). The number of times competed in each competition type at each age group was therefore summarised for each athlete and put forward into the next stage of the analysis. For the sake of brevity, only the results for the highest level of competitive experience both domestically and internationally were listed in the findings.

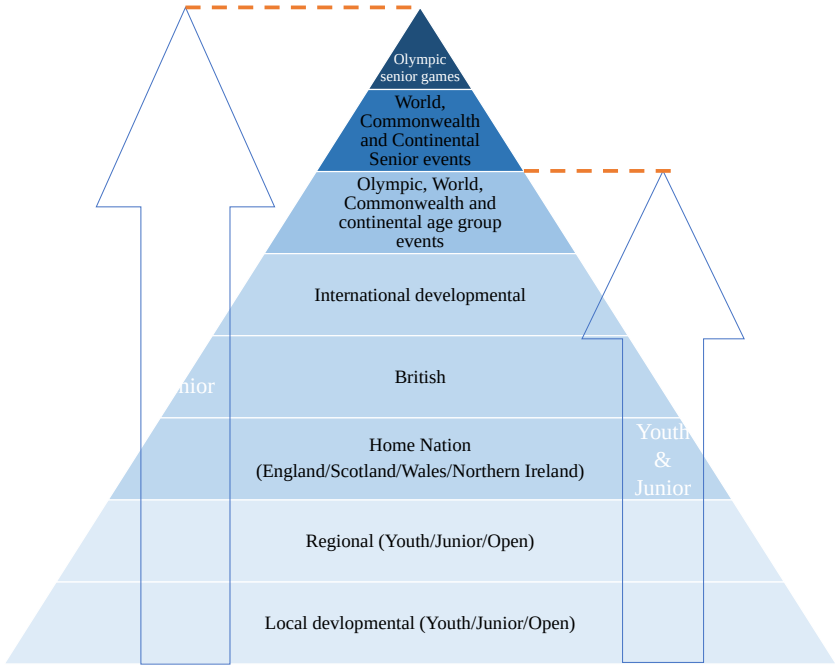

Figure 4. A schematic representation of the performance pathway in British weightlifting.

2.5 Data analysis

2.5.1 Machine Learning

The pathway analysis used advanced data handling to establish a set of parameters for each attribute at each age group. Once the parameter for each attribute had been established, it was then used to establish a rule for each attribute that was based on this estimated parameter. This will follow a 4-part process which will be described in the following section: namely parameter optimization, calculation of odds ratios, followed by feature selection and classification (see section 3.2).

This analysis was performed using both the tidyverse (Wickham et al., 2019) and the rWeka packages in R (Hornik, Buchta, Zeileis, 2009). R is an open-source programming language and statistics and graphics software environment that allows users to perform advanced data manipulation and analytics using source code written by R users (R Core Development, 2019).

This R interface provides a coding environment which allows the iterative machine learning process to be programmed, and thus allows for the process to be fine-tuned in order to reveal specific insights about the parameters associated with the selected attributes. The tidyverse package was predominantly used to perform data processing, whilst the rWeka package, which is an R interface for the WEKA machine learning statistical software package (Witten & Frank, 2005), was used to perform machine learning.

2.5.2 Parameter optimization

In order to establish the parameters that was optimised for each attribute in the data, a sub-vector of parameters was initialised for each attribute. This vector was a sequence of 100 equally distributed parameters starting from the minimum value for each respective attribute in the data and ending at the maximum values. Following this, a set of logical attributes were generated that corresponded to each athlete in the sample being either over or under each respective parameter in the vector. For instance, for the attribute '*competition performance at u15*' with a respective parameter of '*2.5*', the new logical attribute would become *'competition performances at u15 over 2.5',* which would thus allow for the expression of a simple logical statement about the dataset. Moreover, each athlete was assigned a 1 if their value for the given attribute was above the parameter specified in the vector, and 0 if their value was below this parameter. Consequently, a total of 100 logical attributes were generated for each original attribute that appeared in the data.

For each logical attribute, odds ratios, along with respective p-values, were generated for both the top-down and bottom-up samples. The lowest parameter for which the odds ratio p-values were less than 0.05 in both top-down and bottom-up samples were selected as the optimized parameter and was thus was put forward as the final logical attribute. For any cases in which both p values were not less than 0.05, then the lowest parameter was selected for any

logical attribute that had at least one p value less than 0.05, or the lowest parameter of the entire range for any attributes which did not have any significant p values. Odds ratio calculation is discussed in the next section.

2.5.3 Odds ratio estimation

As each respective logical variable in the new logical data was in the form of a binary variable (i.e., 1 if the applied rule was true, 0 if false), a characteristic shared with the elite performance variable (i.e., 1 if the athlete achieve 3 or more totals above the 80th British percentile, 0 if false), odds ratios could be calculated for each logical variable in the data. Odds ratios represent the odds of an outcome given the exposure to a condition and are mainly used to assess the effectiveness of clinical trials. In the current study, odds ratios served as a useful metric to assess the likelihood of attaining high performance as a result of achieving the condition associated with each attribute. It also enabled the assessment of the contribution of each rule associated with each attribute to the attainment of elite performance. Odds ratios are calculated by the following formula:

$$OR = \frac{N\ exposed\ positives\ /\ N\ unexposed\ positives}{N\ exposed\ negatives\ /\ N\ unexposed\ negatives}$$

where a positive case is the outcome of elite performance, whilst the negative case is the outcome of non-elite performance. As can be seen above, odds ratios represent the probability of elite performance as a result of exposure to the logical condition relative to the probability of non-elite performance given the same exposure. As such, odds ratios of 1 represent an equal likelihood of performance status given the exposure to the condition, and odds ratios greater than 1 represent an increased likelihood of elite performance given the exposure to the condition. Odds ratios less than 1 represent a reduced likelihood of elite status or, conversely,

an increased likelihood of non-elite status. Odds ratios were adjusted for small samples using the small method, and p values and confidence intervals were calculated using the Fischer's exact method. A logical attribute was considered a discriminator for high performance if the p values for the associated odds ratio was below 0.05. For any significant logical attribute, a level of importance was determined by combining the size of the odds ratio with the prevalence of occurrence in the respective elite sample (also known as the true positive rate [TPR]), as shown in figure 5. This was achieved by determining the midway point between the odds ratio and the TPR on the respective scales shown in figure 5.

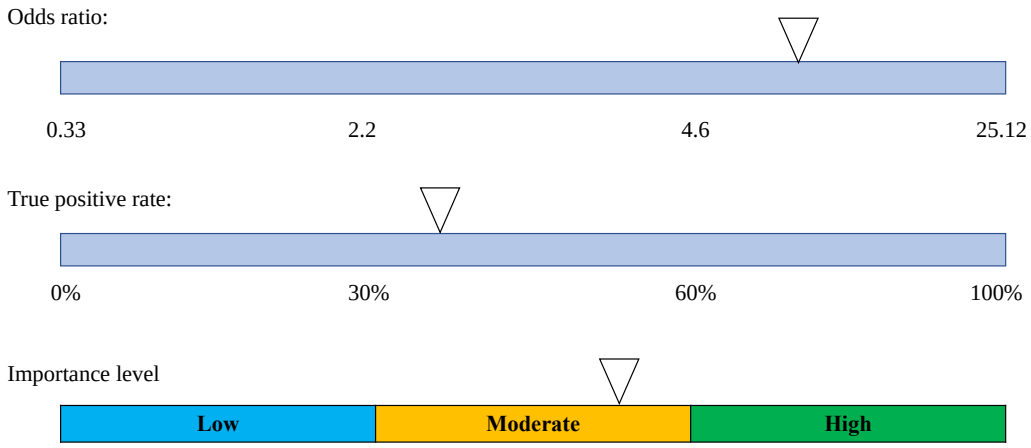

Figure 5. A visual representation of the method used to determine the level of importance of a significant logical attribute. As can be seen, the importance level was determined by finding the midway point between the respective points (represented as arrows) on the odds ratio size and true positive rate scales. An attribute was thus considered highly important if the odds ratio was above 4.6 whilst simultaneously having a true positive rate above 60%.

3. Results

3.1 Logical attributes

The logical attributes that were best selected for each age group in the pathway are presented in table 1 and 2 for women and men, respectively. Note that the importance level

for pathway to next age group was determined from the bottom-up sample, whilst the importance level for the pathway to senior performance was determined from the top-down sample (refer to appendices for a full breakdown of the underlying odds ratios and true positive rates for each logical attribute).

For the women's pathway, these findings provide evidence that both early competitive performances and competitive experience are important factors for the attainment of high performance. Moreover, consistently demonstrating above average performances, as well as acquiring a higher volume of competitive experience, particularly in elite domestic and international competitions, creates an optimal precedent for the pathway to elite performance in the following age group. However, a caveat for this finding is that predictions from as early at u15 was generally not associated with performance at senior, which suggests that high performance from as early as u15 may not be a critical age group for elite senior performance attainment; although moderate evidence exists that demonstrating above average performances in the clean and jerk may be an indicator of weightlifting potential. The findings in relation to the competitive experience at u15 suggests that perhaps exposure to the international stage may be more facilitative in the pathway to elite senior performance than actual u15 performance.

In relation to competitive performances, larger thresholds (>7.5kg) above the predicted value for age, bodyweight, and experience level suggest that performance at u17 should be considerably higher than the average performance for that age group. For competitive experience, these findings suggest that although absolute weightlifting experience (3.8 years or more) is not an essential factor for elite senior performance, evidence for competing in a high volume of competitions at the u17 age group is important for the pathway to senior performance. Moreover, elite domestic and international exposure at u17 are also encouraged. For competitive performance at u20, comparatively higher true

positive rates for the performance related attributes in this section further highlight the significance of attaining elite performance at this age group (see appendices). Findings from this section also reaffirm that early experience in the sport isn't necessarily a prerequisite of elite performance attainment for women athletes, as evidence for years of competitive experience at u20 for the elite senior pathway were negligible, suggesting that competing in weightlifting from as early as 15 years of age did not appear to discriminate performance at the senior age group.

For the men's pathway, elements of the competitive history profile from as early as u13 were identified as moderately important discriminatory features in the top-down analysis. Early competitive exposure was also reflected in the number of competitions at u13, as competing in at least 2 weightlifting competitions at u13 were also moderately important determinants of elite performance attainment at senior. Additionally, competing in and finishing at least 4th in a British youth competition at u13 was identified as a moderately important feature in the senior pathway. Further along the pathway, features from all three pathway themes appeared to be progressively more important for the attainment of senior performance, as table 2 highlights.

Table 1. Logical attributes for the women's performance pathway

Attribute	*Importance for pathway to elite performance at next age group*	*Importance for pathway to elite performance at senior*
Women at u15		
Competitive performances		
Total above norm at u15	High	-
Weight selection in competition		
First attempt for the snatch above norm at u15	High	-
Load increase for the snatch second attempt at least 0.5 kg above norm at u15	Moderate	-
First attempt for the clean & jerk at least 1kg above norm at u15	High	Moderate
Load increase for the clean & jerk third attempt above norm at u15	Moderate	-
Competitive History		
1.7 or more years of competitive experience at u15	High	-
Competed in at least 5 events at u15	High	-
Competed in a British junior event at least 1 time at u15	Moderate	-
Competed in an International developmental junior event at least 1 time at u15	-	Moderate
Competed in a continental youth event at least 1 time at u15	Moderate	-
Women at u17		
Competitive performances		
Total at least 7.5kg above norm at u17	High	Moderate
Weight selection in competition		
First attempt for the snatch at least 3.5kg above norm at u17	High	-
Load increase for the snatch second attempt by at least 0.5 kg above norm at u17	Moderate	-
First attempt for the clean & jerk at least 4.5kg above norm at u17	High	Moderate
Load increase for the clean & jerk second attempt above norm at u17	High	-
Competitive History		
3.8 or more years of competitive experience at u17	Moderate	-
Competed in at least 11 events at u17	High	High
Competed in a British senior event at least 1 time at u17	High	-
Competed in a continental youth event at least 1 time at u17	High	Moderate
Women at u20		
Competitive performances		
Total at least 6.5kg above norm at u20	High	High
Weight selection in competition		
First attempt for the snatch at least 4kg above norm at u20	High	High
First attempt for the clean & jerk at least 3.5kg above norm at u20	High	High
Load increase for the clean & jerk second attempt above norm at u20	Moderate	-
Competitive History		
4.6 or more years of competitive experience at u20	Moderate	-
Competed in at least 12 events at u20	Moderate	Moderate
Competed in a British senior event at least 2 times at u20	-	Moderate
Won a gold medal at a British senior event at u20	High	Moderate

Competed in a world senior event at least 1 time at u20	Moderate	High
Women at u23		
Competitive performances		
Total at least 11kg above norm at u23	High	High
Weight selection in competition		
First attempt for the snatch at least 4.5kg above norm at u23	High	High
Load increase for the snatch third attempt above norm at u23	-	Moderate
First attempt for the clean & jerk at least 6.5kg above norm at u23	High	High
Load increase for the clean & jerk second attempt above norm at u23	-	Moderate
Competitive History		
8.2 or more years of competitive experience at u23	High	Moderate
Competed in at least 11 events at u23	Moderate	Moderate
Competed in a British senior event at least 3 time at u23	Moderate	High
Won a gold medal at a British senior event at u23	High	High
Competed in a world senior event at least 1 time at u23	Moderate	Moderate

Table 2. Logical attributes for the men's performance pathway

Attribute	Importance for pathway to elite performance at next age group	Importance for pathway to elite performance at Senior
Men at u13		
Competitive performances		
Total at least 3kg above norm at u13	Moderate	Moderate
Weight selection in competition		
First attempt for the snatch above norm at u13	Moderate	Moderate
Load increase for the snatch second attempt above norm at u13	-	Moderate
Load increase for the snatch third attempt above norm at u13	-	Moderate
First attempt for the clean & jerk at least 1.5kg above norm at u13	Moderate	Moderate
Load increase for the clean & jerk second attempt above norm at u13	-	Moderate
Load increase for the clean & jerk third attempt above norm at u13	-	Moderate
Competitive History		
0.11 or more years of competitive experience at u13	Moderate	Moderate
Competed in at least 2 events at u13	Moderate	Moderate
Competed in a British youth event at least 1 time at u13	-	Moderate
Finished 4th or higher in a British at u13 youth event	Moderate	High
Men at u15		
Competitive performances		

Total at least 3.5kg above norm at u15	High	High
Weight selection in competition		
First attempt for the snatch at least 1kg above norm at u15	High	High
First attempt for the clean & jerk at least 1kg above norm at u15	High	High
Load increase for the clean & jerk second attempt above norm at u15	-	High
Competitive History		
Competed in weightlifting for 1.8 or more years of competitive experience at u15	Moderate	High
Competed in at least 5 events at u15	High	Moderate
Competed in a British youth event at least 2 times at u15	High	High
Finished 4th place or higher at a British youth event at u15	High	High
Competed in a British junior event at least 1 time at u15	High	-
Competed in an International developmental junior event at least 1 at u15 time	-	Moderate
Men at u17		
Competitive performances		
Total at least 7kg above norm at u17	High	Moderate
Weight selection in competition	Moderate	
First attempt for the snatch at least 8kg above norm at u17	High	Moderate
Load increase for the snatch second attempt above norm at u17	Moderate	-
Load increase for the snatch third attempt above norm at u17	Moderate	-
First attempt for the clean & jerk at least 3kg above norm at u17	High	Moderate
Competitive History		
3.7 or more years of competitive experience at u17	High	Moderate
Competed in at least 6 events at u17	Moderate	Moderate
Competed in a British junior event at least 1 time at u17	High	-
Won a silver medal or higher at a British junior event at u17	High	Moderate
Competed in a world youth event at least 1 time at u17	Moderate	-
Men at u20		
Competitive performances		
Average total more than 27.5kg above norm at u20	High	High
Weight selection in competition		

First attempt for the snatch at least 8kg above norm at u20	High	High
Load increase for the snatch second attempt above norm at u20	-	Moderate
Load increase for the snatch third attempt above norm at u20	-	Moderate
First attempt for the clean & jerk at least 9.5kg above norm at u20	High	High
Load increase for the clean & jerk second attempt above norm at u20	Moderate	Moderate
Competitive History		
6.8 or more years of competitive experience at u20	Moderate	Moderate
Competed in at least 10 events at u20	Moderate	Moderate
Competed in a British junior event at least 2 times at u20	High	High
Won a silver medal or higher in a British junior event at u20	Moderate	Moderate
Competed in a British senior event at least 1 time at u20	High	High
Finished 4th or higher in a British senior event at u20	High	High
Competed in a world junior event at least 1 time at u20	Moderate	High
Men at u23		
Competitive performances		
Average total more than 23.5kg above norm at u23	High	High
Weight selection in competition		
First attempt for the snatch at least 11kg units above norm at u23	High	High
First attempt for the clean & jerk at least 12kg above norm at u23	High	High
Competitive History		
8.6 or more years of competitive experience at u23	Moderate	High
Competed in at least 8 events at u23	Moderate	Moderate
Competed in a British senior event at least 2 times at u23	High	High
Won at least a silver medal at a British senior event at u23	Moderate	-
Competed in a world senior event at least 1 time at u23	High	Moderate

3.2 Feature selection and classification

In order to determine the predictive accuracy of the pathway analyses, a Bayesian pattern recognition analyses was performed on both the bottom-up and top-down samples in the study. For the top-down analyses, a subset of the attributes the best predicted senior elite

performance status was determined for each gender. This final model of features which was to be put forward to classification. Although it is generally advised to consider as wide an interpretation of the pathway analysis as possible, the final features can allow for a streamlined interpretation of the data, and thus for any instances in athlete monitoring procedures which require interpretation of the critical features only. The feature selection process also enables to determine the relative importance of each attribute on the overall pathway. For each bottom-up analyses, the attributes that were selected as important in the previous section were used to classify the respective bottom-up samples, and thus the classification process assessed the predictive power of the significant logical attributes.

3.2.1 Summary models for top-down analyses

The significant logical attributes summarised in tables 1 and 2 were applied to all athletes in the top-down sample, which created a dataset for each gender with binary values based on each athlete successfully meeting the criteria outlined by the logical attributes (i.e., 1 for true, 0 for false). To create the models, feature selection was performed on both logical datasets using four feature selection algorithms: correlation attribute evaluator (CAE), the relief F attribute evaluator (Kira & Rendell, 1992), the support vector machine attribute evaluator (cf. Guyon, Weston, Barnhill, & Vapnik, 2002), and the correlation-based feature selection subset evaluator (CFS; Hall & Smith, 1998). This processed essentially resulted in a ranked sequence of these variables by order of predictive power of elite performance, which resulted in a critical subset of attributes from each dataset which would ultimately be put forward for the classification. This process determined a model of 4 features for the women's pathway, and 8 features for the men's pathway. These attributes are outlined in tables 10 and 11, respectively. For next step in the analysis, the model's ability to differentiate the performance groups was assessed against four different classification algorithms. For this step, four commonly used classification algorithms were used, namely the Naïve Bayes (cf. John & Langley, 1995) , J48

decision tree (cf. Quinlan, 1993), Support Vector Machine (SMO; cf. Platt, 1999) and K-nearest neighbours (Aha, Kibler, & Albert, 1991). This classification process was performed iteratively using a 10-fold cross validation procedure in order to minimise overfitting the findings to the data and thus preserving the generalisability of the resulting model.

Figure 6 displays the radar plot for the final women's pathway model. It would appear that the model for the women's pathway would include a combination of performance attributes in the u20 and u23 age group. This model also emphasizes the prospective importance of competing internationally from as early as u17, which would also imply that performing at a high enough level domestically in order to attain the qualification entry requirements for this level of competition. This model also emphasizes the maintenance of high levels of performance throughout the u20 and u23 pathway. The performance diagnostics of the model can be seen in table 3. Generally, the model was able to correctly classify 88% of the female top-down sample across all four classification algorithms with similar performance. The high sensitivity parameter suggests that the model was able to successfully differentiate 93% of the non-elite sample correctly, whilst the specificity parameter suggests that 70% of the elite sample were correctly classified. An average area under the ROC curve of 0.825 also suggests that the model has a moderate capacity to distinguish performance (Obuchowski, Lieber, & Wians, 2004).

Table 3. Summary statistics for all four classification algorithms for women's pathway model

Classifier	Accuracy	Sensitivity	Specificity	Area under ROC curve
Naïve Bayes	89.8%	0.921	0.818	0.872
Support Vector Machine	87.8%	0.921	0.727	0.824
J48 Decision Tree	85.7%	0.921	0.636	0.778
K-Nearest Neighbour	89.8%	0.973	0.636	0.827
All Classifiers	88.3%	0.934	0.704	0.825

Accuracy = Correctly classified observations / total number of observations. Sensitivity = 1 – false positive rate. Specificity = 1 – false negative rate. Area under ROC curve is a measure of model's ability to correctly distinguish the two groups. ROC = Receiver operating characteristic.

For the male pathway model, performance attributes from as early as the u13 age group were selected and were distributed evenly throughout the pathway (see figure 6). The model placed particular emphasis on clean and jerk performance being sustained throughout the pathway. The model also supports the accumulation of competitive experience from as early as the u15 age group, which suggest that early specialization may be of particular importance for the elite male pathway. This is also supported by the model's suggestion that early exposure to the highest level of domestic senior competition should occur from as early as u20.

Table 4 depicts the performance metrics for the male pathway model. As table 4 shows, the model was able to correctly classify 78.9% of the men's top-down pathway sample. The model appeared to be particularly strong at classifying the non-elite sample (89.7%), whilst 4 in every 10 elite athletes were correctly classified on average (43.8%). The model would therefore seem to suggest that the emphasis placed on early specialization is applicable to 80% of the sample, which leaves approximately 20% of the sample unaccounted for. The relatively low specificity parameter would also seem to suggest that the notion of early specialization better accounts for the avoidance of non-elite performance, as the majority of elite athletes were misclassified by this model.

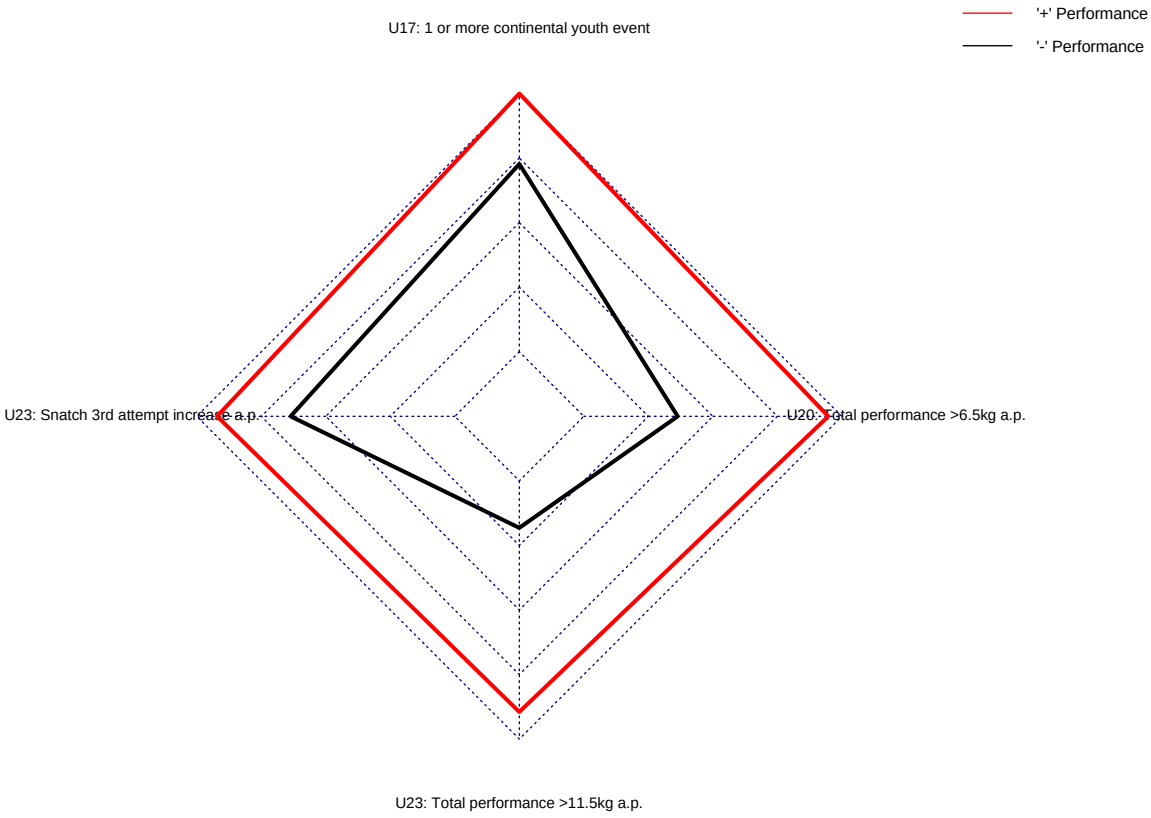

Figure 6. Radar plot depicting the final model of attributes in the women's pathway. Note: a.p. = above predicted

Table 3. Summary statistics for all four classification algorithms for men pathway model

Classifier	Accuracy	Sensitivity	Specificity	Area under ROC curve
Naïve Bayes	84.3%	0.897	0.667	0.888
Support Vector Machine	80.1%	0.846	0.667	0.756
J48 Decision Tree	70.6%	0.872	0.167	0.496
K-Nearest Neighbour	80.4%	0.974	0.250	0.937
All Classifiers	78.9%	0.897	0.438	0.769

Accuracy = Correctly classified observations / total number of observations. Sensitivity = 1 – false positive rate. Specificity = 1 – false negative rate. Area under ROC curve is a measure of model's ability to correctly distinguish the two groups. ROC = Receiver operating characteristic.

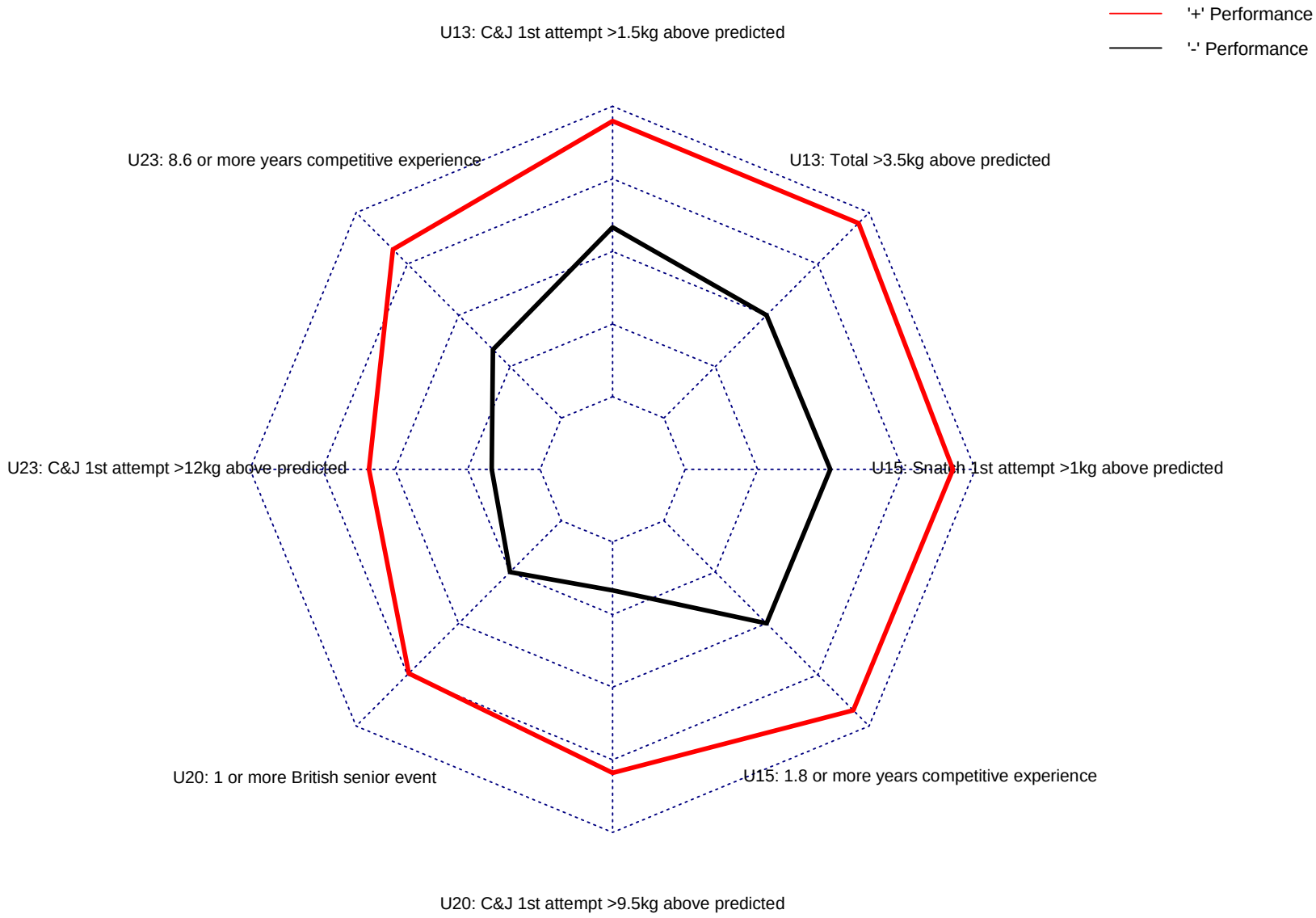

Figure 7. Radar plot depicting the summary model for the men's pathway

3.2.2 Summary models for bottom-up analyses

For each bottom-up analyses performed across the pathways, classification was performed using the Naïve Bayes classification algorithm. This algorithm was selected as it was generally the best performing algorithm across all classification analyses. This would seem logical, as the naïve Bayes algorithm deploys estimates of maximum likelihood that are similar to the odds ratio method. The summary statistics for bottom-up pathway model are shown in table 5.

Table 5. Classification summary statistics for women's and men's bottom-up pathway models

Pathway	Accuracy	Sensitivity	Specificity	Area under ROC curve
Women's pathways:				
Women's u15 to u17 pathway	84.3%	0.881	0.500	0.833
Women's u17 to u20 pathway	92.3%	0.933	0.889	0.864
Women's u20 to u23 pathway	79.4%	0.797	0.778	0.815
Women's u23 to senior pathway	81.3%	0.833	0.750	0.835
Men's pathways:				
Men's u13 to u15 pathway	87.5%	0.941	0.269	0.755
Men's u15 to u17 pathway	85.6%	0.880	0.700	0.865
Men's u17 to u20 pathway	86.8%	0.886	0.700	0.864
Men's u20 to u23 pathway	88.3%	0.903	0.767	0.880
Men's u23 to senior pathway	82.5%	0.863	0.633	0.850

Accuracy = Correctly classified observations / total number of observations. Sensitivity = 1 – false positive rate. Specificity = 1 – false negative rate. Area under ROC curve is a measure of model's ability to correctly distinguish the two groups. ROC = Receiver operating characteristic.

As shown in table 5, all models produced very good area under the ROC curves of 0.755-0.885, and classification accuracies ranges from 79-92%. These results confirm the predictive validity of each attribute in the pathway in predicting short term performance.

An applied example of this classification process is shown in table 6, in which the likelihood of elite performance of four different athletes are calculated by the naïve Bayes

algorithm based on their accomplishments in the u20 age group. As can be observed, athlete A, who had just managed to perform above the norm for the clean and jerk first attempt was assigned with a 0.1% likelihood of elite status, whilst Athlete D, who had more than 4.6 years of competitive experience at u20, had an average first attempt for the clean and jerk above the norm, won a gold medal at a British senior event and competed in a world senior event whilst at u20 was calculated as having 93% likelihood of elite status. It is also noteworthy to observe the differences between athlete B and C. Specifically, whilst the performance achievements were identical, Athlete C had acquired more than 4.6 years' worth of competitive experience up to and including the u20 age group, ultimately resulting in an increased likelihood of elite status. This example demonstrates the holistic competitive profile is taken into account when classifying the status of the athlete. It would therefore be at the discretion of the practitioner or policy maker to determine the accepted threshold for elite status. Any threshold of 50% or above with the naïve Bayes algorithm is generally recommended (Hastie, Tibshirani, & Friedman, 2009).

Table 4. An applied example of the classification process using the Women's u20 to u23 model

Athlete	Pathway Achievements	Predicted Elite
Athlete A	First attempt for the clean & jerk at least 3.5kg above norm at u20	0.1%
Athlete B	First attempt for the snatch at least 4kg above norm at u20 First attempt for the clean & jerk at least 3.5kg above norm at u20 Total at least 6.5kg above norm at u20	15.8%
Athlete C	4.6 or more years of competitive experience at u20 First attempt for the snatch at least 4kg above norm at u20 First attempt for the clean & jerk at least 3.5kg above norm at u20 Total at least 6.5kg above norm at u20	56.2%
Athlete D	4.6 or more years of competitive experience at u20 First attempt for the clean & jerk at least 3.5kg above norm at u20 Competed in a world senior event at least 1 time at u20 Won a gold medal at a British senior event at u20	93.4%

4. Discussion

The current study aimed to investigate the extent with which the attainment of elite performance can be accurately profiled and predicted using machine learning and advanced data handling procedures. Historical performance data was partitioned into separate samples in order to observe the pathway to elite performance attainment both retrospectively and prospectively. It was shown that elite performance attainment can be successfully predicted from the historical profile of athletes with a good degree of accuracy. Specific performance and competition related parameters for each stage of the developmental pathway were also established.

In general, and as to be expected, attributes from all three pathway themes (i.e., competitive performances, weight selection in competition, and competitive history) were moderately to important predictors of performance in the bottom-up analyses for both men and women. For the women's top-down analyses, moderate to important predictors of senior performance became most prevalent from the u20 age group onwards, although some predictors, which mainly centred around clean and jerk performance and competitive experience, were established from as early as the u15 age group. In relation to competitive exposure, the finding that athletes who were exposed to international developmental events from u15 were more likely to achieve elite senior performance highlights the importance of competitive exposure along the pathway to elite performance. This competitive exposure on the international stage, which would include watching other lifters from different countries perform as well as the experience of international travel to participate in the sport, could encourage motivational characteristics to emerge, which could ultimately encourage long term commitment to the sport (Hardy et al., 2017).

For men, however, attributes from all three pathway themes were moderate to important predictors of senior performance from as early as the u13 age group, which would

suggest that early pathway entry is indicative of long-term elite performance attainment for men. The competitive history profiles also suggest that early competitive success as well as exposure were facilitative of long-term elite performance. Perhaps early exposure to regular competition would seemingly offer more affordances for competitive engagement, which would in turn promote higher engagement in deliberate practice that may reflect more pronounced effects on short term performance. Much like the findings reported for female athletes at u15, exposure to an international competition could have fostered the appropriate motivational characteristics for long term commitment to the sport.

From the current findings, two themes have emerged that are worthy of discussion: namely, specialization and athlete transitions. In relation to specialization, these findings would seem to suggest that there was a gender difference in the age at which performance along the pathway would begin to be accountable for performance in the elite senior pathway. This association could perhaps shed light on the age in which athletes should begin to specialize along the pathway. The concept of specialization was initially proposed by Cote and colleagues (2007) in the developmental model of sports participation (Côté et al., 2007). They characterized specialisation as the transition from initial sport participation to significant investment into a sport, and it is often the period in which athletes begin to identify themselves as athletes of the sport (Monsaas, 1985). Specialization has generally been shown to occur between 13-15 years (Côté et al., 2007), although recent research has supported specialization to occur much later, particularly in cgs sports (Moesch et al., 2011).

In relation to the current study, the current findings seem to suggest that earlier specialization could be an important feature in the male pathway, as elite male senior athletes were achieving high performance from as early as the u13 age group, especially in comparison with their non-elite senior counterparts. It must however be noted that this was not an absolute prerequisite for senior performance attainment, as just 41% of the elite senior

sample had specialized early. For the women's pathway, early specialization did not appear to be as important for elite senior performance attainment, as correlates of senior performance were found from the u17 age group onwards. It is thus likely that the female athletes were transferring into weightlifting from other sports at a later stage in the pathway.

The findings in the current study also highlights the important features for transitioning throughout the pathway to elite performance. Whilst the performance related parameters emphasize the importance of performance attainment, the competitive history profiles reflected the importance of competitive exposure on both the domestic and international stages. Of particular prevalence was early exposure to international developmental competitions in both the women's and men's pathway, as well as early exposure to elite domestic competitions. Elite performers were typically exposed to British senior and age group competitions from as early as the u15 age group. These forms of exposure allow for the athlete to effectively bridge the gap between their current performance and their performance potential. These findings also highlight the role of national governing organisations in gatekeeping the transitions between performance levels in the pathways (Sotiriadou et al., 2008).

This study as a whole is the first to demonstrate that historic performance can be sophistically interrogated to reveal potentially important competitive milestones along the performance pathway. These findings therefore present some potentially important applied implications for pathway management. With use of the rules established in the dataset, policy makers could begin to adopt evidence-based strategies in their pathway management procedures, as well as providing education on pathway management that are bespoke to athlete gender. The current study's findings could also begin to encourage coaches and athletes to adopt Bayesian logic in performance analysis, which could in turn promote an evidence-based perspective in terms of prospects for both short and long term.

Whilst this study appears to reflect the pathway demands of athletes on the attainment of elite performance. It arrives at some pitfalls when trying to encapsulate a complete framework for the development of elite performance in weightlifting. It is reasonable to expect past performance to predict future performance, but many questions remain unanswered about the attainment of current performance. These also include any relevant antecedents to elite performance attainment in weightlifting. The remaining chapters will aim to uncover some of the important features whilst using a quasi-experimental approach both prospectively and retrospectively.

Chapter 3

A retrospective enquiry into the holistic development of elite British weightlifters

Abstract

Models of talent development have stemmed from research that have typically examined theoretical themes (e.g., deliberate practice/play and environmental influences) in isolation and have predominantly been analysed using statistical approaches best suited to experimental research. Whilst informative, these models offer a 'one size fits all' framework, and struggle to capture the holistic and dynamic nature of talent development that is relevant to a specific domain of expertise. This study therefore aimed to determine the extent with which elite performance in weightlifting could be explained holistically. Using a retrospective enquiry, the biographical development of 11 elite and 12 non-elite senior athletes was profiled to include the following developmental themes: (1) demographics and family sport participation, (2) sporting history, (3) competitive milestones and (4) weightlifting specific microstructure of practice. Elite performance was best described through a series of empirically derived logical statements from each theme. Qualitative accounts of the athlete's experiences at competitive milestones also detailed the athlete's transition throughout the competitive pathway. The final predictive model classified the groups with 85% accuracy. The fundamental components of expertise attainment, as well as their important antecedents, are discussed.

KEYWORDS: talent development; talent identification; expertise development; Olympic weightlifting; machine learning

1. Introduction

The prediction of performance on the basis of historic performance has been shown to be accurately represented (see chapter 2). Using advanced data handling and machine learning algorithms, the non-linear profiling of athletes based on their historic performance data was used to accurately estimate the likelihood of future elite performance attainment. The underlying message of these findings generally lend support to the concept that high performance today can predict high performance tomorrow. However, whilst this may be important from a talent identification perspective, several questions remain unanswered with regard to the factors that contribute to the attainment of high performance in weightlifting to begin with. Moreover, if applied practitioners were to base their decisions to invest coaching resources into an athlete based solely on historic performance, then they run the risk of overlooking some of the fundamental components of elite performance that could ultimately discard the potential for future performance. One could draw comparisons to investing in a company's stock solely based on its current value in the market versus considering the underlying drivers behind a company's potential for future success. The underlying mechanism of the attainment of high performance in weightlifting, thus, warrants further investigation.

The development of high performance in sport stems from a dynamic interplay of a multitude of features (Fransen & Güllich, 2019). A considerable body of theoretical frameworks, along with supporting evidence, have illuminated the construct of expertise development over the past 30 years. However, it is in capturing this dynamic interplay between these frameworks and features, that poses logistical problems for the practitioner and policy maker. Moreover, problems exist when trying to determine which features appear to be more influential than others, particularly when consolidating past research that has (1) predominantly studied factors influencing performance development in relative degrees of

isolation and (2) have used statistical approaches that are best suited to experimental and epidemiological research.

In a recently published position stand commissioned by UK sport, the quality of existing evidence from a broad range of factors influencing the attainment of elite sports performance were explored and recommendations for policy makers and practitioners were outlined (Rees et al., 2016). Moreover, whilst proposing avenues for future research, Rees and colleagues invited research to embrace the complexity and multidisciplinary nature of talent development. This review has since given rise to a recent body of research that has utilized cutting-edge machine learning data analytics to approach this problem (Güllich et al., 2019; Hardy et al., 2017; Jones et al., 2019). This machine learning approach has allowed for the selection of a critical set of features in the developmental biographies of athletes that best discriminate between two pre-determined athlete groups (e.g., super-elite versus elite). This critical set can then be used to inform the narrative that best describes the attainment of high performance for the population of interest. This approach, underpinned by a theoretically driven framework spanning multiple disciplines, enables for a much richer mechanism for conceptualising expertise development. Additionally, since data science techniques are in the advent of big data, the potential breadth in exploring the dynamic development of expertise is now as wide as it has ever been.

However, the current body of research using these techniques have predominantly explored differences in athletes who were selected from a range of different Olympic sports (Güllich et al., 2019; Hardy et al., 2017), and as such the themes that have emerged from these findings may not necessarily be best suited to the specific characteristics of a single sport. To date, only one study has explored the multidisciplinary determinants of expertise develop in a single sport (Jones et al., 2019). Using a retrospective research design, Jones and colleagues investigated the relative contributions of a set of 93 multidisciplinary attributes on

the development of elite performance attainment in cricket spin bowlers. The authors found that a subset of 12 of these 93 attributes classified elite athletes with 100% accuracy. Interestingly, was the fact that this final model retained the multidisciplinary nature of expertise development that was specific to the domain in question (i.e., spin bowling), thereby emphasising the need for future research to deploy this methodology to other domains of sporting expertise.

The aim of the current study, therefore, was to use a machine learning approach to investigate the extent to which elite performance in weightlifting can be holistically profiled. Specifically, whilst utilizing the theoretical framework discussed in chapter 1, this study used a retrospective recall paradigm to explore the extent with which features in the biographical development of elite senior weightlifting athletes can be used to accurately differentiate them from that of their non-elite counterparts.

2. Method

2.1 Participants

Twenty-three current and past senior weightlifting athletes took part in the study (11 females, 12 males, mean age = 24.3 ± 5.2). The invitations for these studies were administered from the national governing body for weightlifting in Wales. All athletes were informed that the research project formed part of a national talent identification programme for the 2022 commonwealth games, and as such were informed about the specific aims of the study. Ethical approval for the study was granted by the committee for Ethics at the school of sport, health, and exercise sciences, Bangor university.

So that athlete identity could be preserved for any qualitative accounts throughout the study, athletes were randomly assigned an alphabetic letter as their first initial, followed by a “E” or “NE” depending on their subsequent classification as an elite or non-elite athlete, respectively.

2.2 Procedure

All athletes were invited to participate in a structured interview which detailed their developmental experiences throughout their formative years. The interview lasted approximately 3 hours, in which athletes were asked a specific series of questions that covered four broad developmental themes: (1) demographics and family sport participation, (2) sport participation history and weightlifting specific involvement, (3) competitive milestones in weightlifting, and (4) weightlifting specific practice activities. The interview was structured to cover any potential environmental influences in section 1, whilst athlete specific developmental experiences were covered in sections 2 through to 4. So that any relevant changes to an athlete's developmental experience over time could be recorded, questions in sections 2 to 4 were repeated in relation to their occurrence at each of the following three age groups: by age 12, age 15, and age 19. The ages were set to approximately match the early, middle, and later years of athlete development (Balyi, 2001; Bloom, 1985). Quantitative responses were recorded on a spreadsheet for further processing. Audio recordings of the interviews were also transcribed verbatim and were retained to provide qualitative support for any findings.

2.3 Measures

A total of 387 features was collected and encoded for each athlete. These features are listed in table 7.

Table 7. Features used as part of the multidimensional profiling

1. Demographics and familial sport participation ***1.1 Familial sport participation***
Mother involvement in sport, mother experience in weightlifting, father involvement in sport, father experience in weightlifting, same sex sibling, older same sex sibling, same sex sibling experience in weightlifting
1.2 Homeplace throughout development:
Population of longest residing homeplace between 6-12 years, population density of longest residing homeplace between 6-12 years, population of longest residing homeplace between 13-15 years, town population of longest residing homeplace between 13-15 years, times relocated throughout development

1.3 Schooling
Attended sport school between 6-12 years, attended sport school between 13-15 years, school main place for sport participation between 6-12 years, school main place for sport participation between 13-15 year.
1.4 Relative Age
Month of birth (1 = January 12 = December), birth quarter (calendar and school; Q1 = Jan-Mar [calendar], Q1 = Sept – Nov [school]), relative age to nearest aged sibling (in days).
2. Sport History and Weightlifting Specific Involvement ***4.1 Sport Involvement (between ages 6 – 12, 13 -15, and 16-19 years):***
Years involved in each of the following sports: athletics, badminton, basketball, boxing, cricket, CrossFit, dance, football, golf, gymnastics, handball, hockey, horse riding, martial arts, motorsports, mountain biking, rounders, rowing, rugby, swimming, tennis, diving, trampoline; years between 6 and 12 years involved in individual sports, team sports, and cgs sports; total number of sports; years between 13 and 15 years involved in individual sports, team sports, and cgs sports; total number of sports; years between 16 and 19 years involved in individual sports, team sports, and cgs sports; total number of sports
4.2 Weightlifting specific and related involvement (between ages 6 – 12, 13 -15, and 16-19 years):
Number of competitions per year, exposure to competition (hours/year), time spent in competition (hours/year), flexibility/mobility training (hours/week), number of months involved in weightlifting training (hours/week), weightlifting specific practice (hours/week), strength & conditioning training (hours/week)
3. Competitive milestones in weightlifting ***3.1 Domestic representation (by ages 12, 15, and 19):***
Highest level of domestic representation, age of first appearance at highest domestic representation level, rank of first appearance at highest domestic representation, technical challenge of highest domestic competition, psychological challenge of highest domestic competition
3.2 International representation (by ages 12, 15, and 19):
Highest level of international representation, age of first appearance at highest international representation level, rank of first appearance at highest international representation, technical challenge of highest international competition, psychological challenge of highest international competition
3. Microstructure of practice ***5.1 Sport Involvement (between ages 6 – 12, 13 -15, and 16-19 years):***
Deliberate practice vs play, mental skills training, vicarious experiences, conveying of information, whole/part practice, constant vs varied practice, specificity of practice, focus of attention, prescriptive versus constraints coaching

2.4 Data Analysis

2.4.1 Machine Learning

Machine learning was implemented in the current study in order to provide a set of rules from which group membership could be best classified. Machine learning normally follows a 2-part process: feature selection followed by classification (cf. Güllich et al., 2019; Jones et al., 2019). Feature selection is the process from which the relative importance of the features in the dataset is determined based on their predictive validity for classifying group membership. A critical subset of the features, usually of a predetermined size, is then established based on the ordering of each feature's relative importance (the highest *n* ranked features are ultimately selected as the model of *n* size). The second step, termed classification, then utilizes classification algorithms to assign each participant with an expected group membership based on their respective scores on each feature.

This process normally enables the dimensions in the data to become significantly reduced and subsequently allows for the relationships between the groups to be best described using a critical set of features. This would also allow for the features that do not contain predictive validity to become removed from consideration, allowing for a more efficient approach to describing the patterns in the data. However, in the context of expertise development, in which many complex dynamics occur, this process can lead to the unselected features to becoming somewhat overlooked, and thus may become discarded as unimportant. This could potentially lead to a reductionist description of expertise development which may only tell a part of the whole story. Additionally, commonalities amongst the groups, which could serve to describe necessary prerequisites for embarking on pathway to elite performance to begin with, could also be ignored.

Thus, whilst the importance of feature selection in this study ought not to be discarded, the current study endeavoured to utilize feature selection in such a way that doesn't over reduce the multidisciplinary nature of dataset. Specifically, this study will aim to establish a set of parameters for each feature that will be estimated from the data which will then establish a rule

for each attribute that is based on this estimated parameter. A subset of these new rules will then be determined by feature selection, which will then be put forward to classification. Therefore, the machine learning approach in this study will follow a 4-part process which will be described in the following section: namely parameter optimization, odds ratio estimation, feature selection, followed by classification (see section 4). This analysis was performed using the rWeka package in R (Hornik, Buchta, & Zeileis, 2009), which is an R interface for the WEKA machine learning statistical software package (Witten, Frank, & Hall, 2011).

2.4.2 Group classification

The models that were produced in chapter 1 of the thesis was used to classify the athletes in the current sample. Specifically, all athletes were classified using the Naïve Bayes algorithm on each of the bottom-up models at each respective age group pathway (u15 to u17, u17 to u20, u20 to u23, and u23 to senior). Each model performed estimation of the probability of elite performance in the succeeding age group. This estimation considered the following themes within the competition data at the relevant age group: (1) competitive performances, (2) weight selection in competition, and (3) competition history. As such, any athlete for whom the predicted likelihood of elite performance exceeded 50% in any of the models was classified as elite in the sample. This resulted in the classification of 11 athletes as elite (6 female, 5 males, mean age = 25.2 ± 6.2), and 12 athletes as non-elites (5 female, 7 males, mean age = 23.5 ± 3.9).

2.4.3 Parameter optimization

In order to establish the parameters that would be fed forward into feature selection, a vector of parameters centred on the mean for the high-performance group was initialised for each attribute in the dataset. This vector was a sequence of 100 equally distributed parameters starting from 3 standard deviations below the mean for the high-performance group and ending at 3 standard deviations above the mean for the same group. Following this, a set of logical

attributes were generated that corresponded to each observation being either over or under each parameter in the vector. Moreover, each athlete was assigned a 1 if their value for the given attribute was above the parameter specified in the vector, and 0 if their value was below this parameter. Consequently, a total of 100 logical attributes were generated for each original attribute in the data.

In order to determine which of the newly generated logical attributes contained the most predictive power for classifying the two groups, feature selection was then performed for each set of 100 logical attributes using a combined rank of the following four feature selection algorithms: correlation attribute evaluator (CAE), the relief F attribute evaluator (Kira & Rendell, 1992), the support vector machine attribute evaluator (cf. Guyon, Weston, Barnhill, & Vapnik, 2002), and the correlation-based feature selection subset evaluator (CFS; Hall & Smith, 1998). This process essentially resulted in a ranked sequence of these variables by order of predictive power. The logical variable that was identified as containing the most predictive power was then put forward for odds ratio estimations. This resulted in a newly generated dataset containing logical variables, or 'rules', for each original attribute in the dataset. Consequently, the 387 original attributes were now converted to logical rules that were based on an optimized parameter of the attribute.

2.4.4 Odds ratio estimation

As discussed in chapter 2, odds ratios represent the probability of high-performance as a result of exposure to the logical condition relative to the probability of low performance given the same exposure. Odds ratios were calculated using the same methodology as that used in chapter 2. Odds ratios were adjusted for small samples using the small method, and p values and confidence intervals were calculated using the Fischer's exact method. A logical rule was considered a discriminator for high performance if the p values for the associated odds ratio was below 0.05. Conversely, for any logical rules that did not appear as discriminators,

commonalities were determined on the basis that (1) a high proportion of each group (approximately 60% or more) met the condition, and (2) the logical attribute contained theoretical relevance as a commonality. These commonalities amongst the sample could thus be identified as a necessary baseline condition to become involved in weightlifting to begin with.

3. Results

3.1 Odds ratio estimations

3.1.1 Demographics and family

3.1.1.1 Commonalities

3.1.1.1.1 Parental involvement in sport

A commonality amongst the senior samples in relation to demographics and familial sport participation was in relation to parental involvement in sport (see table 8). Specifically, at least 72% of both high performing and low performing samples had a mother or father who was themselves involved in sport participation. When asked about their parental sporting involvement, J-NE said:

> *My mum I think she did karate when she was younger. That stopped when she had me at a young age. Now she's kind of all over the shop, she does marathons, she cycles she does kettle bell kind of conditioning and all the classes and stuff like that so just kind of general exercise. My dad was [playing] rugby from a young age. He was playing up until around 7 years ago I think and then just stopped because of a knee injury.*

Similarly, G-E also reported that both of his parents were involved in sport:

> *Definitely in school I remember her talking about it doing a lot of running. That was across different distances so cross country, she used to hurdle as well and do a bit of*

sprinting. She's only five foot so as she got older, she realised hurdling wasn't really for her. She played a lot of hockey when she was younger. She used to instruct at swimming and stuff, but I never knew of her weightlifting. I can't remember my dad ever talking about playing anything other than for fun with his mates. A bit of football, a bit of cricket, you know but it was like kids going out to play after school kind of thing. He has always been active. He has always been doing stuff but never sort of competitively.

3.1.1.1.2 Population density

The density of the town population also appeared to be a commonality amongst the senior sample, particularly for the homeplace town during the early formative years (i.e., between the ages 6 to 12). Nine out of 12 non-elite athletes, and all 11 elite athletes lived in a town with a population density of at least 913 pop per km^2 between the age of 6 and 12 years.

Table 5. Logical attributes with estimated odds ratios for all common and discriminative features.

Attribute	Non-Elite	Elite	OR (95% CI)	Importance
1. Demographics and familial sport participation				
Homeplace throughout development				
Population of longest residing homeplace between 6 to 12 years over 6,392	7/12 (58.3%)	11/11 (100%)	6.88 (0.81 - 351.8)	High
Density of longest residing homeplace between 6 to 12 years over 912.49	9/12 (75%)	11/11 (100%)	3.3 (0.39 - 185.35)	-
Familial Sport participation				
Father involved in sport	11/12 (91.7%)	8/11 (72.7%)	0.17 (0.04 - 2.61)	-
Mother involved in sport	10/12 (83.3%)	8/11 (72.7%)	0.36 (0.09 - 3.71)	-
2. Sport History and Weightlifting Specific Involvement				
Sport participation throughout development				
Number of sports sampled:				
Sampled at least 1 sport at age 6	10/12 (83.3%)	8/11 (72.7%)	0.36 (0.09 - 3.71)	-
Sampled at least 1 sport at age 7	10/12 (83.3%)	9/11 (81.8%)	0.55 (0.13 - 6.43)	-
Sampled at least 1 sport at age 8	11/12 (91.7%)	10/11 (90.9%)	0.42 (0.08 - 10.19)	-
Sampled at least 1 sport at age 9	12/12 (100%)	10/11 (90.9%)	0 (0.01 - 7.62)	-
Sampled at least 2 sports at age 10	7/12 (58.3%)	3/11 (27.3%)	0.21 (0.06 - 1.59)	-

Sampled at least 3 sports at age 11	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Sampled no more than 1 sport at age 18	10/12 (83.3%)	11/11 (100%)	2 (0.23 - 127.73)	-
Years involved in each sport between 16 – 19 years:				
Individual Sport for more than 2 years	7/12 (58.3%)	11/11 (100%)	6.88 (0.81 - 351.79)	High
Weightlifting related involvement:				
Flexibility/mobility training (hours per week) at:				
Age 14 more than 0.56 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Age 16 more than 2.02 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Strength & Conditioning Training (hours per week):				
Age 6 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 7 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Weightlifting specific practice (hours per week):				
Age 6 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 7 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 8 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 9 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 10 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 13 more than 2.02 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age 14 more than 4.51 hours	1/12 (8.3%)	6/11 (54.5%)	5.5 (1.17 - 70.07)	Moderate
Total combined flex/mob, strength & conditioning, and weightlifting specific practice (hours per week):				
Age 6 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 7 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 11 more than 1.12 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age 12 more than 1.17 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age 13 more than 2.66 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Age 14 more than 4.34 hours	2/12 (16.7%)	8/11 (72.7%)	6.67 (1.59 - 65.39)	High
Age 15 more than 8.66 hours	1/12 (8.3%)	8/11 (72.7%)	11 (2.26 - 153.3)	High
Age 16 more than 12.49 hours	2/12 (16.7%)	7/11 (63.6%)	4.67 (1.15 - 42.68)	High
Age 19 more than 20.01 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Competitions per year:				
Age 14 at least 2 competitions	1/12 (8.3%)	6/11 (54.5%)	5.5 (1.17 - 70.07)	Moderate
Age 15 at least 4 competitions	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Cumulative hours spent in competition (per year):				
Age 13 more than 2.52 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age 14 more than 1 hour	2/12 (16.7%)	7/11 (63.6%)	4.67 (1.15 - 42.68)	High

Cumulative practice volumes by age 15:				
Flexibility/mobility practice over 106.93 hours	1/12 (8.3%)	7/11 (63.6%)	7.7 (1.62 - 100.67)	High
Strength & Conditioning training over 416.88 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Weightlifting specific practice over 552.97 hours	1/12 (8.3%)	7/11 (63.6%)	7.7 (1.62 - 100.67)	High
Number of competitions over 3	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Cumulative practice volumes by age 19:				
Flexibility/mobility practice over 673.1 hours	2/12 (16.7%)	8/11 (72.7%)	6.67 (1.59 - 65.39)	High
Strength & Conditioning training over 581.41 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Weightlifting specific practice over 2123.28	3/12 (25%)	8/11 (72.7%)	4.5 (1.15 - 37.81)	High
3. Competitive milestones in weightlifting				
By 15				
Domestic representation				
Highest domestic representation level by 15 at least British Youth	1/12 (8.3%)	6/11 (54.5%)	5.5 (1.17 - 70.07)	Moderate
Age of first appearance at highest domestic level by 15 under 14.75	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Psychological challenge of highest domestic competition by 15 under 5/10	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
By 19				
Domestic representation				
Highest domestic representation level by 19 was British Senior	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age of first appearance at highest domestic level by 19 under 16.88	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Technical challenge of highest domestic competition by 19 under 7/10	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
International representation				
Highest international representation level by 19 at least continental youth	0/12 (0%)	7/11 (63.6%)	16.8 (1.96 - 887.56)	High
Psychological challenge of highest international competition by 19 over 6/10	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
4. Microstructure of practice				
Deliberate Practice vs Play				
By 15				
Proportion of deliberate play at least 19%	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Volume of deliberate play more than 56.3 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Volume of deliberate practice more than 492.63 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
By 19				

Volume of deliberate practice more than over 1952.99 hours	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Mental skills training (hours per week):				
By 19 over 572.86 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Vicarious Experiences:				
By 15 over 80.82 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
By 19 over 73.75 hours	1/12 (8.3%)	8/11 (72.7%)	11 (2.26 - 153.3)	High
Information conveyed to the athlete:				
By 19				
Over 4% video information	4/12 (33.3%)	9/11 (81.8%)	4.8 (1.18 - 43.5)	High
Whole/Part Practice				
For the Snatch:				
By 15				
Volume of snatch part practice by 15 over 125.3 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Volume of snatch whole practice by 15 over 96.8 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
By 19				
Volume of snatch part practice by 19 over 684.7 hours	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Volume of snatch whole practice by 19 over 238.3 hours	1/12 (8.3%)	7/11 (63.6%)	7.7 (1.62 - 100.67)	High
For the Clean & Jerk:				
By 15				
Volume of clean & jerk part practice by 15 over 190.81 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Volume of clean & jerk whole practice by 15 over 147.6 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
By 19				
Proportion of clean & jerk practice as parts under 78%	4/12 (33.3%)	10/11 (90.9%)	8 (1.69 - 103.46)	High
Proportion of clean & jerk practice as whole movement over 21%	4/12 (33.3%)	10/11 (90.9%)	8 (1.69 - 103.46)	High
Volume of clean & jerk part practice by 19 over 764.7 hours	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Volume of clean & jerk part practice by 19 over 197.7 hours	1/12 (8.3%)	8/11 (72.7%)	11 (2.26 - 153.3)	High
Constant vs Varied Practice				
By 15				
Volume of practice with constant practice more than 333.42 hours	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
By 19				
Volume of practice with constant practice more than 1586.2 hours	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Volume of practice with varied practice more than 67.5 hours	1/12 (8.3%)	8/11 (72.7%)	11 (2.26 - 153.3)	High
Specificity of Practice				

Anxiety Specificity:				
By 15				
Proportion of overall practice over 35%	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Volume of Anxiety Specificity training over 164 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
By 19				
Proportion of overall practice over 9%	4/12 (33.3%)	9/11 (81.8%)	4.8 (1.18 - 43.5)	High
Volume of Anxiety Specificity training over 342.14	0/12 (0%)	7/11 (63.6%)	16.8 (1.96 - 887.56)	High
Context Specificity:				
By 15				
Volume of context specificity training over 16.09 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
By 19				
Context Specificity Difficulty rating by 19 at least 4/10	3/12 (25%)	8/11 (72.7%)	4.5 (1.15 - 37.81)	High
Volume of context specificity training over 348.57 hours	1/12 (8.3%)	8/11 (72.7%)	11 (2.26 - 153.3)	High
Focus of Attention				
By 15				
Volume of practice with external focus of attention over 270.81 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
By 19				
Source of feedback				
By 19				
Proportion of intrinsic feedback over 51%	1/12 (8.3%)	7/11 (63.6%)	7.7 (1.62 - 100.67)	High
Prescriptive versus constraints coaching				
By 15				
Proportion of practice with constraints-based coaching at least 11%	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Volume of practice with constraints-based coaching over 88.4 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
By 19				
Proportion of practice with constraints-based coaching over 11%	2/12 (16.7%)	7/11 (63.6%)	4.67 (1.15 - 42.68)	High
Volume of practice with constraints-based coaching over 434.3 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate

3.1.1.2 Discriminators

3.1.1.2.1 Population of homeplace through development

Whilst the population density appeared to be an important commonality amongst the weightlifting sample, the absolute population size appeared to discriminate between the

samples. More specifically, all 11 of the high performing sample had lived in a district with a population of at least 6,392 inhabitants between the age of 6-12 years, whilst this was prevalent in just 7 of the 12 non-elite athletes. This would therefore seem to suggest that towns with larger populations would seem to have the appropriate infrastructure necessary to foster participation and subsequent development of high performance in weightlifting. This would also be supported by the views of J-E:

> *Even though I was competing at national level as a kid, in [her second sport], we still did swimming so we both went to a swimming club, we did that once a week we then started tennis in our early teens so we both played tennis together as well which was quite good. So, we were generally always active we always had a sporty childhood. I think my mum saw it as I guess in a way allowing us to burn our energy off, but when you have a facility which is why I find [sporting venue] so important. We got to explore so many sports that we wouldn't have had the opportunities to than if we were in a different area and we wouldn't have had the access to those facilities and that structure.*

This would therefore suggest that the population of the longest residing homeplace is an important feature in the development of high performance in weightlifting, which is in accordance with the original premise of the birthplace effect (Côté et al., 2006).

3.1.2 Sporting history and weightlifting related involvement

3.1.2.1 Commonalities

3.1.2.1.1 Sport Participation throughout sampling years

Sampling of sports during the early developmental years also appeared to be an important commonality amongst the senior sample. At least 70% of either sample had participated in at least 1 sport from as early as age 6 through to age 9. Given that most of the sample also had a parent involved in sport themselves, this commonality could have most likely emerged through parental encouragement to participate in sport from an early age.

Another commonality amongst the sample was in relation to the number of sports involved from age 18. Ten out of the 12 non-elite, and all eleven elite athletes reported to be involved in no more than 1 sport from the age of 18 onwards. Taken together with the early onset of weightlifting involvement that will be discussed in the following sections, this would suggest that many of the athletes were engaged in weightlifting alongside other sports throughout their earlier developmental years, perhaps before beginning to invest significantly more in weightlifting when approaching the age of 18.

3.1.2.2 Discriminators

3.1.2.2.1 Sport Participation throughout sampling years

Whilst it is clear that the majority of the sample were involved in least 1 sport from as early as 6 years of age, evidence also existed that the number of sports sampled later in the development appeared to discriminate weightlifting performance. Specifically, 4 of the 11 elite athletes had sampled at least 3 sports at the age of 11, whilst sampling these many sports was not observed in any of the non-elite sample until the age of 12 onwards. These findings would generally suggest that the elite sample were engaged in more sampling from an earlier age.

3.1.2.2.2 Weightlifting related involvement

3.1.2.2.2.1 Flexibility/Mobility training

Elements of reported weightlifting related involvement throughout development also appeared to discriminate elite performance attainment in the current sample. Evidence for these findings predominantly occurred during what is commonly referred to as the middle years of development (i.e. age 13 - 15 onwards; Bloom, 1985; Côté et al., 2003). The first discriminating feature in this section was in relation to the number of hours dedicated to flexibility/mobility training from the age of 14. Specifically, 5 of the 11 elite athletes were completing at least 0.56 hours (approximately equivalent to 30 minutes) of flexibility and mobility training per week, whilst none of the non-elite sample were reporting this. This relationship was also apparent at

the age of 16, as 4 of the 11 high performing athletes were completing at least 2 hours of flexibility and mobility training at this age, whilst none of the non-elite athletes were completing these volumes at 16. One of the elite athletes, C-E, who took part in gymnastics from a young age, attributed her flexibility training to her involvement in gymnastics:

> *Well I started gymnastics from the age of 5 so I was always doing a lot of flexibility and mobility work. We would also be doing a lot of general conditioning then, but I would definitely say flexibility training was a big part of my gymnastics.*

3.1.2.2.3 Weightlifting specific practice

In addition to weightlifting related involvement, the weightlifting specific practice activities during the middle developmental years also appeared to be important discriminating features of weightlifting performance in the current sample. More specifically, 4 of the 11 elite athletes were engaged in at least 2 hours of weightlifting specific practice at 13 years of age, whilst none of the non-elite sample had reported this. This volume had increased to 4.51 hours per week, from which 6 of the 11 elite athletes were typically completing these volumes, whilst just 1 of the 12 non-elite athletes were.

These findings are also extended to the total combined weightlifting specific and related practice involvement. Specifically, 4 of the 11 elite athletes were completing at least 1 hour of combined weightlifting related and specific involvement at age 11, which was not replicated in any of the non-elite sample. This volume had increased to 12.5 hours per week by the age of 16, from which 7 of the 11 elite athletes, and just 2 of the non-elite sample were completing this volume. At age 19, 4 of the 11 elite athletes were completing at least 20 hours of combined flexibility, conditioning, and weightlifting specific technical training each week, which was not replicated in any of the non-elite sample. When discussing her transition into the later stages of the pathway, J-E said:

I think the transition to becoming a senior international squad member just after age 15 increased my desire and intensity to perform and channel all energy into the sport, but more so the high-performance athletes I was training with motivated me. The training increased in strength building although we still continued with the other elements of plyometrics, fitness and conditioning to continue my development.

A specific breakdown of this weightlifting related involvement will be discussed in section 4.

Exposure to higher volumes of competition time throughout development was also an important discriminator of weightlifting performance in this senior sample. More specifically, 6 of the 11 elite athletes had competed in at least 2 weightlifting competitions at the age of 14, whilst just 1 of the 12 non-elite athletes had achieved this. Additionally, 5 of the 11 elite athletes has competed in at least 4 competitions the following year at age 15, whilst none of non-elite athletes had completed this. This had also transpired into at least 2.5 or more hours of time spent in competition at age 13, which had been attained by 4 of the 11 elite athletes, and none of the 12 non-elite athletes. Seven of the 11 elite athletes had also acquired at least 1 hour of competition experience at age 14, whilst just 2 of the 12 non-elite athletes had completed this.

3.1.2.2.4 Cumulative practice volumes

Given that the weekly volumes of weightlifting specific and related practice appeared to discriminate performance, it is to be expected that the cumulative volumes of practice, particularly at later stages in the development, also discriminated performance (see table 8). This was particularly prevalent by 15 and 19 years of age. Specifically, by 15, 7 of the 11 elite senior athletes had amassed at least 107 hours of flexibility and mobility training, whilst just 1 of the 12 non-elite athletes had acquired this. This had increased to 673 hours of flexibility

training by 19, as 8 of the 11 elite, and just 2 of the 12 non-elite, had acquired these volumes. Additionally, 5 of the 11 elite athletes had acquired at least 417 hours of strength and conditioning training by 15. This volume was reported to increase to 581 hours by 19, as 4 of the 11 elite athletes had completed this volume of strength and conditioning and none of the non-elite athletes had attained either amounts of volumes at 15 or 19. For weightlifting specific activities, 7 of the 11 elite athletes had acquired at least 553 hours of weightlifting specific practice by 15, whilst just 1 of the non-elite sample had acquired this. Additionally, 8 of the 11 athletes had acquired a total of 2,123 hours of weightlifting specific practice by 19, which was observed in just 3 of the 12 non-elite athletes. Acquiring these volumes of weightlifting practice resulted in being 4.5 times more likely to attain elite at senior performance. Additionally, four of the 11 elite athletes had also acquired a higher volume of competitive experience by 15, as 4 of the 11 elite athletes had competed in at least 3 competitions by 15, whilst none of the 12 non-elite athletes acquired this.

3.1.3 Competitive milestones and pathway challenge

3.1.3.1 Discriminators

3.1.3.1 Domestic representation by 15

Consistent with the theme throughout the study thus far in terms of volumes of practice from as early as 15, the competitive milestones from as early as 15 also appeared to be a discriminative feature in the development of elite senior performers. Specifically, the 6 of the 11 elite senior athletes reported their highest level of domestic representation by 15 to be at least a British youth competition, which would typically include all age group up to and including the u17 age group. Just 1 of the 12 non-elite athletes reported this by 15.

Additionally, 5 of the 12 elite athletes had competed at their highest level of domestic representation by 15 approximately three months before their 15th birthday. When asked to

report the level of psychological challenge of their first exposure to this level of competition, five of the 11 elite athletes reported a difficulty of no more than 5/10. This would seem to suggest a relatively moderate psychological challenge for these athlete's initial encounter to this level of competition by 15. This had not been reported in any of the non-elite athletes. When asked to describe her experiences of this competition, C-E had mentioned that she was used to the competitive environment through exposure to competition whilst playing her other sport:

> *I guess my technique wasn't as good back then as it is now because I wasn't too far off just starting weightlifting, so I was still learning. But I don't think the competition environment was that much of a challenge because I had competed a lot before in [other sport] so I was used to doing it anyway.*

Similarly, when recalling his competitive experience, R-E mentioned the relaxed environment in these competitions:

> *I just remember it being extremely laid back. I think it was pretty relaxed because it was an u17 competition so there wasn't going to be that many impressive lifts as such. It was just quite nice to be surrounded by kids my own age and looking into the crowd and just seeing parents rather than other older competition. It was a pretty relaxed environment I would say.*

R-E also recalled a specific encounter that caused him to fail at attempt without being too psychologically affected:

> *So I remember on my opening snatch two things happened, as I was walking up to the platform one of the referees stopped because I had to roll my singlet up and then I think that put me off and then when I was lifting I caught it at the bottom and then I ran forwards and almost dropped the bar on the centre judges head! So, for me just because of the inexperience I didn't really know the consequence of missing a lift. I thought if I*

miss a lift I just miss a lift whereas now I know because how valuable lifts are in a competition so I mean I wasn't really that fussed if I made or missed the lift so it probably wasn't that much of a challenge for me.

Similarly, J-E describes her first exposure to a British senior competition from a young age taking her by surprise but without being highly psychologically challenging:

I remember sitting down my mum was there she went a brought a programme because I didn't know it was a British seniors, [my coach] had just told me it's a women's competition there was going to be older women there but my job was just to get experience and enjoy it so I took what he said and didn't really pay much attention to it. So, I remember my mum passing me the programme and I looked at the front and it said British senior women weightlifting championships and I just thought "oh my god!". But apart from that psychologically there was no stress at all, it was literally just, apart from realising it was a senior competition, I was suddenly like wow, but after that I was relaxed and just went through the motions. So, I don't think psychologically it was that hard at all.

3.1.3.2 Domestic representation by 19

The highest level of domestic representation by 19 also appeared to be a discriminative feature of elite performance. Specifically, 4 of the 11 elite senior athletes reported competing in a British senior competition by the age of 19. For six of the 11 elite senior athletes, their first exposure to their highest domestic level of representation took place just before the age of 17. This early exposure would perhaps allow for a smoother transition into the next level of representation in the performance pathway. Additionally, five of the 11 elite athletes reported a technical challenge of this initial exposure as being no higher than 7/10. Conversely, there were a few non-elite athletes who reported this initial exposure as being very challenging psychologically. For instance, when discussing his first exposure to a

home nation senior competition, J-NE describes how his thought process was affected after difficulties of failing an attempt in the warmup room:

> *This comp, going in, it was an intimidating thing because it wasn't just a small comp anymore, it was just a developmental competition. These lifters were hitting huge weights, it was very real you see. I admit I felt very nervous and I thought that when I started in the back I missed [opening weight] on the snatch and seeing everyone else hitting those massive weights it was like oh my god this is not happening right now, so the nerves just hit me massively it really did and I remember I was like oh no its happening and it kind of threw me off because I wasn't concentrated enough.*

3.1.3.3 International representation by 19

The highest level of international representation by 19 also appeared to discriminate performance in the current sample. Specifically, 7 of the 11 elite sample reported competing in at least a continental youth competition by 19. Contrary to the ratings of their domestic experiences, four of these elite athletes also reported a psychological challenge of the first exposure to this level of competition of at least 6/10 or more. Whilst documenting their experience of this competition, G-E said:

> *[That competition] was not good for me. I got to the venue nearly a kilo overweight. I was pretty much kept in the sauna to lose weight so that was a big learning curve for me as far as comp prep. It was hard not because of the technical level of competition, but because of the physical state I was in leading into the competition. So that was again something I had never experienced. I have never experienced having to [lose that much weight], it sucked the life out of me, so I would say that was probably the most fatigued I had lifted, and probably one of the most fatiguing [competitions] I have ever lifted at. I had never had to battle that whole physical barrier where everything feels so hard because of the physical state you're in. So, having to*

concentrate so much on being technically good to make sure you are efficient in your lifts, whereas when you're not in that physical state you can kind of bank on the fact that you're fast or you've got strong legs. [When you're that fatigued] all that is taken away from you and you have to concentrate solely on the technical aspects of the lift.

This would appear to suggest that exposure to the elite international stage offers specific and unique challenges that can only be experienced on the international stage. J-E described the challenges of lifting on a stage that had spotlights in warm weather:

I remember it had massive spotlights on the platform, and obviously with spotlights comes heat, and so loads of people were fainting on clean and jerks because of the heat and obviously if they've had to cut weight….I remember going really dizzy so I just got rid of the bar really quickly.

This would also include the challenge of establishing relationships and trust from other athletes on the squad. H-E describes the difficulties of experiencing challenges from other members of her squad as well as the international stage:

It was definitely a challenge leading into that competition. Being a smaller lifter, I never really had too much challenge at British level because there were always only 2 or 3 lifters in my weight class. There were even some comments from some other lifters in my own squad that said they don't think I should have been selected to be part of this squad. So, that tied in with the fact that it was the world stage just added to the pressure, I think.

3.1.4 Microstructure of practice

3.1.4.1 Discriminators

3.1.4.1.1 Deliberate practice and deliberate play

Evidence for the proportions of deliberate play as important discriminating features of elite performance existed in the senior weightlifting sample. More specifically, five of the 11

elite athletes reported that at least 19% of their practice by 15 was deliberate play. Additionally, four of the 11 elite athletes reported acquiring more than 56 hours of deliberate play by 15, as well as more than 493 hours of deliberate practice. By 19, the volume of deliberate practice that best discriminated elite performance was 1,953 hours, as 6 of the 11 elite athletes had acquired this volume. None of the non-elite athletes had acquired these volumes of practice. When discussing their perspectives on training during their early weightlifting involvement, G-E said:

> *It was all play back then, pretty much. I can't say when I first started, I was going to do these sessions and train this hard and this is where I want to be. I just kind of took it as it was and whatever happened kind of thing. At that age I was still playing [other sport] and doing loads of other stuff as well, so I didn't focus on weightlifting in that kind of way.*

Similarly, R-E, who started weightlifting from 15 years of age, said this about his early weightlifting involvement:

> *I would probably say at the time just getting to know the technique and all the rules and everything I'd probably say more like 60% fun and just enjoying it and then 40% was probably working on the technique and trying to actually get stronger.*

3.1.4.1.2 Volume of Mental Skills Training

The volume of mental skills training acquired by the age of the 19, also appeared to discriminate elite performance. Mental skills training referred to the amount of time during a typical week which was spent mentally rehearsing their own performance routines (usually through imagery) or reflecting on past training and competition experiences. Four of the 11 elite athletes had acquired more than 573 hours of mental skills training by 19 years of age. Athletes typically reported weekly volumes of approximately 3 or more hours per week. This

cumulative volume was not replicated in any non-elite athletes. When asked to recall how often she engaged in mental skills training, H-E said:

> *I would say three of four hours per week. After a session I would probably think of it, go over it, think about what I could have done better, watching videos, I'll probably think about it before I go to bed. I think about it a lot.*

3.1.4.1.3 Vicarious experiences

Evidence for the volumes of vicarious experiences in elite athletes appeared to discriminate the samples. Vicarious experiences referred to the experiences undergone as a result of observing other athletes prepare for and compete in training and competition. Five of the 11 elite athletes had amassed at least 81 hours of vicarious experiences by 15, whilst none of the non-elite sample had managed this. Additionally, 8 of the 11 elite sample had acquired at least 74 hours of vicarious experiences by 19, which was reported in just 2 of the 12 non-elite sample.

It is likely that these experiences could have taken the form of watching more experienced athletes train and compete at the same venue in which the athlete trains. G-E gives a brief encounter of his early vicarious experiences:

> *Occasionally we used to train after school. It was 90% lunchtime but there was two lifters that was lifting at the time who would either come in at the end of a lunchtime and either train in the day if they weren't working or like the occasions that we were allows to train in the evening they'd be there. I used to weigh [a small amount of] kilos for my first competition, so I was little, and [the older weightlifter] used to clean and jerk like 140, 150, 160 kilos and it was like wow! I could have sat and watched him for ages. As a young kid it was just like "woah he's got more than one disc on the bar", and that was like a big thing.*

Additionally, given the relatively high volume of vicarious experiences reported, it is likely that these experiences could have taken the form of additional time spent outside of typical training time. This could have been through watching weightlifting competitions live or televised, or through conversations with friends or siblings involved in weightlifting.

3.1.4.1.4 Video feedback

The type of information that was conveyed to the athletes also appeared to discriminate elite performance attainment in the current sample. Evidence for this finding was predominantly in the proportions of the different feedback types that were conveyed. Specifically, higher proportions of elite athletes were receiving more video feedback at later stages in the pathway. Moreover, nine of the 11 elite athletes reported receiving more than 4% of their information from their coach in video format at 19, whilst only 4 of the 12 non-elite athletes reported this. R-E mentioned that the long distance between him and his coach meant that the feedback that he had received from his coach was mainly in relation to video information:

> *At that point my coach generally wasn't with me for my session as they are based [away from main training venue], so I would send them videos and they would give me feedback based on those videos. So, I would say we've used videos more so at 19 than we did before.*

3.1.4.1.5 Whole versus part practice

The volumes of whole and part practice for the snatch also appeared to discriminate between the samples. More specifically, 5 of the 11 elite athletes had acquired more than 125 hours of part practice for the snatch, and more than 97 hours of whole practice for the snatch by 15. None of the non-elite sample has managed to acquire this. Moreover, by 19, six of the 11 elite athletes had acquired a volume of part practice for the snatch of more than 685 hours, which was not observed in any of the non-elite sample. Seven of the 11 elite athletes had also

acquired more than 239 hours of whole practice on the snatch by 19, whilst this was observed in just 1 of the 12 non-elite sample.

For the clean and jerk, evidence for both the proportions of whole and part practice, as well as the respective volumes of practice as discriminatory features of performance was present in the current study. Specifically, 5 of the 11 elite athletes had reported acquiring a practice volume for the clean and jerk part practice of at least 191 hours. Additionally, 4 of these elite athletes had also reported a practice volume of at least 147 hours for the clean and jerk part practice. None of the non-elite sample had acquired this volume.

Additionally, and interestingly, 10 of the 11 elite athletes had reported practicing the clean and jerk as parts for no more than 78% of their overall practice by 19, whilst just 4 of the 12 non-elite sample reported this. This was also reflected in the respective volumes of practice, as 6 of the 11 elite sample had reported acquiring a volume of at least 767 hours of part practice for the snatch, whilst none of the 12 non-elite sample reported this by 19. For the clean and jerk, 8 of the 11 elite athletes also reported volumes of whole practice of more than 198 hours by 19, whilst just 1 of the 12 non-elite sample reported these volumes.

3.1.4.1.6 Constant versus varied practice

The volumes of both constant and varied practice from as early as 15 appeared to discriminate performance in the current sample. Specifically, 6 of the 11 elite athletes had reported a volume of constant practice of more than 333 hours by 15, which was not replicated in any of the non-elite sample. This volume of constant practice had increased to 1,586 hours by 19, with the same athletes acquiring this volume of practice. Additionally, 8 of the 11 elite athletes reported acquiring more than 68 hours of varied practice by 19 years of age, whilst just 1 of the 12 non-elite athletes reported these volumes. When asked about whether their practice environment varies, C-E said:

I wear the same footwear and stuff all the time. I lift on similar platforms all of the time and there might be sometimes where I have to move and stuff like that, so I'd say it's probably about 75% constant. When its busy and I've had to share with somebody else really. And sometimes there might be a class on you tend to lift this side of the class usually anyway. I will sometimes switch platforms, so sometimes I go on the first second or third really.

Similarly, M-E recalls deliberately adding variation to his practice environment:

So, [at my university gym I tried to lift on the same platform every single day, but when I'm back home we'd try and alternate the platform every session so it's something different to look at every session and I think that just something that works well. Because what happens I don't know let's say if you're in a competition and then something changes in front of you, you can't always rely on one fixed point because a lot of people look at a point on the wall, I certainly do, and when that varies that can freak people out sometimes.

As supported by the account of both C-E and M-E, the most prominent occurrence of varied practice conditions reported by the athletes in the current study was in relation to the variance in the environments in which they trained. This mainly included training in different weightlifting clubs, or at different locations in the same weightlifting club. When training at different weightlifting clubs in particular, athletes would be encouraged to perform their usual training routine with varied perceptual constraints, such as surrounding visual or auditory information, or task constraints, such as different lifting surfaces or equipment.

3.1.4.1.7 Specificity of practice

Both the proportions and volumes of anxiety specific practice by 15 and 19 appeared to discriminate elite performance in the senior sample. Specifically, 4 of the 11 elite athletes reported that at least 35% of their overall practice volume was anxiety specific by 15, which

was not applicable to any of the non-elite sample. This had transpired to the accumulation of more than 164 hours of anxiety specific practice by 15, as 5 of the 11 elite athletes had acquired this volume. By 19, 9 of the 11 elite sample reported that at least 9% of their overall practice included elements that induced the same emotional responses that as experienced during competition. This was reported in just 4 of the 12 non-elite athletes. The resulted in a threshold of 342 hours of anxiety specific practice by 19. When discussing how her training can induce the specific emotions experienced in competition, H-E mentions that this mainly occurs as the intensity of her training increases:

> *When the weights get heavier like we are in blocks now leading up to a comp then the pressure is probably a lot greater. It is self-inflicted but I would probably say it's like a 7 out of 10. I can talk myself out of it but it's still there.*

The volume of context specific practice also appeared to differentiate between the performance groups. More specifically, 5 of the 11 elite athletes had accumulated at least 16 hours of context specific practice by the age of 15, which was not achieved by any of the non-elite athletes. By 19, this volume had increased to 348 hours of practice, as 8 of the 11 elite athletes, and just 1 of the 12 non-elite athletes had achieved this. Proportionately more elite athletes also rated the difficulty of this context specific practice as higher than 4 out of 10, whilst just 3 of the 12 elite athletes had rated above this. When discussing the prevalence of their practice that was context specific, C-E mentioned that this would normally occur when their training block approaches competition:

> *Usually in training I don't really set up as comps. We do usually go up the same snatch and clean and jerks' sort of numbers. But it depends on what I'm doing in training, sometimes I'll do [two maximum repititions] in training or sometimes I might do [three maximum repititions]. I guess closer to comp we do try and keep it similar. Like*

especially the two sessions before comp I do lift the same how I would snatch and clean and jerk. I have actually timed my rest periods to make sure they are the same in comp.

On the other hand, H-E mentioned that they always try to keep rest periods in training as specific as they would be in competition:

I try and time my lifts to 2 minutes every session, when it comes to openers and things like that it depends on the phase or training block.

3.1.4.1.8 Focus of attention

The proportion of practice with an external focus of attention also appeared to be positively associated with elite performance. More specifically, by 15, five of the 11 elite athletes had acquired at least 270 hours of practice with an external focus of attention. Additionally, 6 of the 11 elite athletes had acquired at least 290 hours of practice with an external focus of attention. This was not achieved by any of the non-elite athletes. In order to promote an external focus of attention, H-E describes the very unique occurrence of how her coach would make her sing the same song whilst performing her lifts:

My coach told me to sing a song in my head before I lifted and the exact same words, I had to execute my lift. And it was at that point that I started to make my lifts because I wasn't overthinking it anymore. I wasn't thinking of "pull the bar, move your feet", at that point it was an automated movement and I didn't need to think about it was either going to go up or it wasn't so just sort of put everything came into place.

It would therefore appear to suggest that adopting an external focus of attention would limit H-E from paying too much attention to what would otherwise be a natural movement. However, not all elite athletes reported explicitly adopting this external focus, and that they would mostly alternative between attentional foci. For example, when asked about that nature of their attentional focus, CE said:

It varies depending on what I'm working on, so at the minute I'm working on my bottom position in the snatch, so I judge it on how I feel at the bottom. Sometimes I used to just sink into the bottom instead of just standing straight up. So, it depends on what I'm working on really.

3.1.4.1.9 Sources of feedback

Evidence for the proportion of augmented feedback that was internally generated also appeared to differentiate performance in the current study. This was particularly prevalent at later stages in the age pathway. Specifically, 7 out of 11 elite athletes reported generating more than 51% of their total feedback from intrinsic sources, whilst just 1 of 12 non-elite athletes reported this. This was mostly attributable to having to develop their own feedback whilst practicing alone. When discussing the nature of their feedback, M-E highlighted a unique method to developing his own feedback.

I work on sounds. I know it sounds stupid, but I like to think about the sound it makes when I lift and if I know that it makes contact when I hear [makes sound], then it knows it's good. So, I always think [makes sound] whenever my hips touch the bar and if it sounds like that then great. If I don't think about the sound, then it might sound [incorrect] because I'm not applying myself to make that sound.

When asked if it's something developed with practiced, M-E replied:

Yeah, it's just something I've picked up. Even [my coach] when he coaches, I wouldn't say he uses sounds, but he'll always say if I'd done something a bit soft, he doesn't have to use words, he'll always be like [makes sound] and well just sort of get it. That's just through exposure, there's no need for words unless there's a need for words. Same in a comp. You know if he wants more from you, he'll look at you. If you've done well, hell nod and that's enough. You don't need anything else.

This finding would therefore seem to suggest that, through exposure to feedback from external sources, normally from their coach, athletes would eventually begin to recognise any faults in their performance themselves and would start to develop their own feedback at later stages in the pathway.

3.1.4.1.10 Prescriptive versus constraints-based coaching

The proportion and volumes of constraints-based coaching during both the middle and later years of development appeared to be discriminate of elite performance in the current sample. Specifically, by 15, 4 of the 11 elite athletes reported that at least 11% of their overall weightlifting specific practice included some form of constraints-based coaching. The amounted to a volume of approximate 88 hours of practice in these athletes. This was not achieved in any of the non-elite athletes by 15. Additionally, by 19, 7 of the 11 elite athletes, and 2 of the 12 non-elite athletes reported proportions of constraints-based coaching of at least 11% of overall practice. Four of the 11 elite athletes also acquired at least 434 hours of practice with constraints-based coaching, which was not achieved by any non-elite athletes.

3.2 Feature selection and classification

A summary model was produced using a Bayesian pattern recognition analysis to determine the final model of features which was to be put forward to classification Although it is generally advised to consider as wide an interpretation of the athlete's development as possible. As previously mentioned, the final features can allow for a streamlined interpretation of the data, and thus for any instances in athlete monitoring procedures which require interpretation of the critical features only (e.g., such as that in computer software applications). To create the model, feature selection was performed on all normalised attributes in the data (such that the minimum and maximum values for each attribute was represented as 0 and 1, respectively).

Table 9. The list of attributes selected for the summary model, along with their rating of importance and direction of influence on weightlifting performance.

Attribute	Importance level	Direction of influence	
		Elite	Non-elite
Weightlifting related involvement:			
1. Total combined weightlifting related and specific practice by 12	Important	+	-
2. Flexibility/mobility training at age 14 (hours per week)	Important	+	-
Whole versus part practice:			
3. Proportion of whole practice for the clean and jerk by 19	Fairly important	+	-
Specificity of practice:			
4. Volume of anxiety specific practice by 15	Important	+	-
5. Proportion of anxiety specific practice by 19	Very Important	+	-
Competitive Milestones			
6. Highest international level of representation by 19	Fairly Important	+	-

This process determined a model of 6 features which were grouped into three distinct levels of importance based on their appearance in the top 20 features of all four, any three, or any two of the FS algorithms, respectively. Table 9 shows the features in this final model. For next step in the analysis, the model's ability to differentiate the performance groups was assessed against four different classification algorithms. For this step, four commonly used classification algorithms were used, namely the Naïve Bayes (cf. John & Langley, 1995), J48 decision tree (cf. Quinlan, 1993), Support Vector Machine (SMO; cf. Platt, 1999) and K-nearest neighbours (Aha et al., 1991). This classification process was performed iteratively using a leave one out cross-validation procedure in order to minimise overfitting the findings to the data and thus preserving the generalisability of the resulting model. The result of this

classification process can be seen in table 10. As table 10 shows, the model was able to differentiate 86% of the sample across all four classification algorithms successfully. The average sensitivity parameter suggests that the model was able to successfully identify the non-elite sample with 100% accuracy, whilst the specificity parameter of .71 suggest that 71% of the elite sample was correctly classified on average. An average area under the curve (AUC) of 0.81 also indicates that this model contains moderate predictive power (cf. Obuchowski, Lieber, & Wians, 2004). The final model with normalised group means is shown as a radar plot in figure 7. As is shown, clear separation exists between the groups on each attribute in the model.

Table 10. Summary statistics for all four classification algorithms

Classifier	Accuracy	Sensitivity	Specificity	Area under ROC curve
Naïve Bayes	91.3%	1.000	0.818	0.886
Support Vector Machine	87.0%	1.000	0.727	0.864
J48 Decision Tree	82.6%	1.000	0.636	0.746
K-Nearest Neighbour	82.6%	1.000	0.636	0.758
All Classifiers	85.9%	1.000	0.705	0.813

Accuracy = Correctly classified observations / total number of observations. Sensitivity = 1 – false positive rate. Specificity = 1 – false negative rate. Area under ROC curve is a measure of model's ability to correctly distinguish the two groups. ROC = Receiver operating characteristic.

4. Discussion

This multidimensional study set out to investigate the extent with which elite performance in weightlifting can be explained holistically. With the aid of machine learning and advanced data handling techniques, this study demonstrated that the attainment of elite performance in weightlifting can be described holistically using a series of empirically derived logical statements. Additionally, a critical subset of these features was shown to differentiate elite performers from their non-elite counterparts well beyond the level of

chance. The current findings will be discussed in the context of the framework for expertise development adopted throughout the study.

4.1 Demographics and familial sport participation

The observation of the athlete's wider demographics and family involvement in sport uncovered some key indicators of elite performance attainment, whilst some key commonalities amongst the sample were also found. These findings highlight the importance of affordances for engagement in sampling and play in the athlete's formative experiences. Specifically, residential districts above a threshold of population density and size would more than likely have the infrastructure which offers the facilities and services for early sport sampling and deliberate play (Rossing et al., 2016). It would appear that high performing athletes in the current study spent the majority of their formative years in residential districts that could offer such services. However, whilst a minimum threshold for population size and density does appear to be important features, it should not be without consideration that a trade-off should exist between absolute population size and density, and competition for developmental resources (i.e., coaching time and use of facilities) which would occur particularly in larger and more densely populated communities.

In addition to the influence of homeplace throughout development, the parental influence on sport participation also appeared to be an important prerequisite for elite performance attainment in the current sample (see section 3.1.1.1.1). This had also been widely reported in the research literature (see Fredricks & Eccles, 2005). One specific interpretation of this notion is that parents effectively depart specific values and or belief systems to their children, which ultimately forms the basis of that child's set of values. Should participation in sport be a part of those values, perhaps through encouragement to partake in and sample sports from an early age, then the subsequent likelihood of the child fostering these aforementioned motivational factors should also be increased.

4.2 Sporting history and weightlifting related involvement

Commonalities and discriminators of weightlifting performance were also apparent in the sporting history profile of the athletes. More specifically, and likely as a consequence of parental sporting influence, both elite and non-elite athletes were participating in at least 1 sport from as early as 6 years of age, which later diversified into wider sport sampling as they approached the middle years of development (i.e., 13 to 15 years). Subsequent specialization in weightlifting then occurred from approximately 18 years of age. A key discriminator of weightlifting performance, however, appeared to be the number of sports sampled from an earlier age, as the elite athletes tended to participate in more sports at least a year earlier in their development (i.e., from as early as 11 years of age).

These findings therefore reaffirm the direct benefit of early diverse sport participation on subsequent elite performance attainment, which would appear to be in line with the literature supporting the benefits of early diversification on sports performance (Baker, 2003; Güllich, 2017). A key feature of this diversification is the development of physical adaptations to sport and exercise, which includes the development of general motor skills (Fransen et al., 2013) and preparation for future learning (Bransford et al., 1999). Additionally, early diversification has been proposed to account for the opportunity to engage in playful activities which would foster the motivational characteristics to engage in higher volumes of deliberate practice at later stages of one's development (Côté et al., 2003a).

The findings also revealed that differences in the athlete's performance could be accounted for by differential exposure to the specific practice activities throughout the athlete's development. Specifically, early weightlifting specific and related exposure tended to be characterized by participation in flexibility and mobility training, as well as weightlifting specific technical practice from as early as 12 years of age. These findings would appear to suggest that an early onset of flexibility training would encourage the adaptations deemed most

appropriate for elite weightlifting performance. As well as involvement in flexibility-related sports, such as gymnastics, this flexibility training was likely performed alongside strength-based activities, which could have promoted both flexibility and strength based neuromuscular adaptations in elite athletes at early stages in their development. These findings also therefore support the notion of engagement in high volumes of deliberate practice being an important component of elite performance attainment (Baker & Young, 2014; Ericsson et al., 1993), as early exposure to these forms of training ultimately resulted in higher cumulative volumes of practice later in the elite athletes development.

4.3 Competitive milestones and pathway challenge

In addition to the antecedents and components of practice activities, the specific developmental experiences encountered also appeared to be important features in the development of high performance in weightlifting (see section 3.1.3). The specific implications of these developmental experiences are that they should be challenging enough to the athlete to meet their specific skill level (Guadagnoli & Lee, 2004). As was typically observed, elite athletes tended to be introduced to the highest level of domestic competition very early in their development with little prevalence of technical or psychological challenge. It was not until they were introduced to the international stage did, they meet higher demands of challenge. This could therefore suggest that, so that they could adapt to the level of challenge encountered, elite athletes should be introduced to the international stage from as early as possible. This finding is also be similar to the notion of the rocky road paradigm (Collins & MacNamara, 2012), which proposes that a high degree of challenge in the developmental experiences of the athlete, dispersed with periods of adjustment, should foster the appropriate psychological adaptations to stress, resulting in a more robust psychological framework for dealing with adversity (Dienstbier, 1989).

4.4 Microstructure of practice

Later in the athlete's development, typically from the age of 15 years of age onwards, practice activities tended to be characterized by a specific prevalence of practice activities and training environments that were accompanied with more intrinsically derived forms of feedback. These findings further support the original tenets of the challenge point framework, which specifies that practice should progressively meet the task demands that are set out by increasing levels of expertise (Guadagnoli & Lee, 2004). The specific practice activities that were uncovered will be discussed below:

4.4.1 Deliberate play

Whilst it is clear that the current findings do indeed support the notion that the volume of time dedicated to developing one's own performance through deliberate practice is a fundamental and necessary component of the attainment of elite performance (Baker & Young, 2014; Ericsson et al., 1993), its prevalence in the current sample of athletes appears to occur as a result of to deliberate play. It is broadly accepted that the engagement in high volumes of deliberate practice is effortful and, for the most part, not inherently enjoyable (Ericsson et al., 1993), and athletes who are better able to sustain intrinsic motivation should, in theory, be better equipped to sustain engagement in deliberate practice. This intrinsic motivation is indeed a complex construct in and of itself and is likely composed of a dynamic interplay of psychosocial features which are beyond the scope of this study. However, as proposed in early frameworks of sport participation, the development of intrinsic motivation can be fostered by early engagement in deliberate play (Côté, Baker, & Abernethy, 2003b), such as that attained through sampling a range of sports throughout the formative years. This could have most likely occurred in the elite sampled in the current study, as the findings show an increased prevalence of sport sampling throughout the early sampling years (see section 3.1.2.2.1). Additionally, the elite weightlifting athletes reported higher proportions and volumes of deliberate play

specifically in their early weightlifting involvement, which also could have contributed to the subsequent engagement in deliberate practice.

4.4.2 Video feedback

The finding that increased exposure to video feedback was discriminative of elite weightlifting performance is a somewhat interesting one, as this suggests the need for some of the information that is presented to the athlete to come from visual sources. This finding could be explained in terms of implicit and explicit motor learning (see Patterson, Pierce, Bell, & Klein, 2010, for a review). Implicit learning refers to the learning of tacit knowledge without intention, after which it becomes difficult to verbalise once learned. This form of learning mainly occurs through observation without the use of explicit instruction which has been shown to lead to more robust performance under pressure (Beilock & Carr, 2001; Masters et al., 2008). It is therefore likely that the information that was presented to the elite group could have facilitated implicit learning, which could have enabled the athletes to engage in the motor learning process without conscious awareness. This reduction in conscious awareness has been shown to reduce the likelihood of constrained action execution (Beilock & Carr, 2001). It is therefore likely that this form of learning could have perhaps encouraged the elite athletes to engage in executing more efficient movement patterns, which in turn could have facilitated more efficient strength adaptations, as well as robustness of movement recall under pressure (Verburgh, Scherder, van Lange, & Oosterlaan, 2016).

4.4.3 Whole versus part practice

Evidence for both the proportions of whole and part practice, as well as the respective volumes of practice as discriminatory features of performance was present in the current study. The general notion of the findings were that elite athletes tended to engage in higher volumes of both whole and part practice than their non-elite counterparts. This finding would conform to the notion of higher volumes of deliberate practice. Of particular interest, however, was the

finding that elite athletes practiced higher proportions of whole practice for the clean and jerk, particularly at later stages of their development. Specifically, these findings suggest that at least one fifth of practice for the clean and jerk should be practiced as a whole movement at later stages in the athlete's development. In line with the premise of whole practice, this would be in order to promote the motor systems to organise throughout the whole movement (Naylor & Briggs, 1963). This would leave the remainder of the practice for the clean & jerk to be dedicated to practicing the snatch as constituent parts. Due to the inherent taxing nature of weightlifting on the underlying energy systems, practicing a whole practice allows for organisation and consolidation of the motor programme (Fontana et al., 2009), particularly when the movement is also broken down and practiced as separate parts.

Whilst the benefits of part practice should not be discarded, there are two potential reasons why clean and jerk whole practice should be more beneficial for performance development. The first is that the clean and jerk in itself is a movement comprised of two discrete movements, in which the transition between these two distinct movements (as well as the phases within each movement) must be fully integrated in order to promote organization of the overall motor programme. Although beneficial for simplifying the learning process (as well as promoting skeletal muscle adaptions), breaking these movements down into chunks creates further distinction between these movements, and as such increasing the proportion of time spent in part practice would compromise the necessary practice time for the integration of these movements during whole practice (Cohen & Sekuler, 2010).

The second reason stems from the specificity of practice principle. As will be discussed shortly, the specificity of practice principle asserts that the demands of practice should aim to be as specific to practice as possible (Henry, 1968). Moreover, the quality of the available information to the athlete and coach, particularly in terms of knowledge of the outcome of the movement, is optimal when the whole motor programme is executed as it intended or

competition. When asked about their experiences of whole versus part practice in weightlifting, G-E's response tended to agree with the underlying tenets of the whole versus part literature:

> *I'm an advocate of just keep it simple and specific, I think. If you can do ten sessions a week then great but with keeping it like that as well there was lots of other ways, I was getting work done without doing any variations or focusing solely on one movement which would be from the block or from the hang or wherever. I've lifted bigger weights since I've been back doing this type of programme than I ever did when I was training full time and doing all the different variations and stuff. So, I think that the variations are important when you are young to a degree, probably not as much as I've done and you could do a little less than that, but ultimately people only get comfortable doing snatch and clean and jerk actually doing snatch and clean and jerk.*

4.4.4 Constant versus varied practice

Athletes in the current study, particularly in the elite sample, also reported practicing in environmental conditions which were varied. These varying constraints are proposed to elicit adaptive and functional movement solutions in the athlete, which in turn supports the stability and flexibility of the performers behaviour (Araújo et al., 2006; Davids, Araújo, Hristovski, Passos, & Chow, 2012; Seifert, 2012; Seifert et al., 2014). This assertion stems from concepts of ecological psychology (Gibson, 1979), and dynamical systems theory (Kelso, 1995; Phillips et al., 2010) which conceptualises the regulation of human behaviour as a complex interaction between the performer with their environment (see Seifert, Komar, Araújo, & Davids, 2016, for a review), and one in which the performers motor system can flexibly adapt to environmental perturbations to achieve perceptual-motor stability and thus allows for reproducible emergent behaviours (Van Emmerik & Van Wegen, 2000). This flexibility can be further enhanced with expertise due the enhanced associations between perceptual

constraints and movement solutions (Davids & Araújo, 2010; Fajen, Riley, & Turvey, 2009; Richardson, Shockley, Fajen, Riley, & Turvey, 2008). For example, Boschker et al (2002) demonstrated that rock climbing experts were able to recall more functional properties of a climbing wall (such as the graspability and reachability), whilst inexperienced rock climbers reported mainly structural aspects (e.g. size and colour) which were of less functional relevance (Boschker, Bakker, & Michaels, 2002).

4.4.5 Specificity of practice

It is also apparent from these findings that practice with conditions that are specific to the demands of competition, both in relation to anxiety and context, are important features for the development of high-performance in weightlifting. This finding lends to notion of the specificity of practice principle (Henry, 1968), which proposed that the best learning experiences stem from those that most closely approximate the target behaviour and environmental context. Moreover, practice conditions that closely meet the demands of competition are proposed to encourage the optimization of available sensory information which is likely to be encountered during competition, even to the extent that transfer to different competition conditions disregards this sensory store, which in turn disrupts performance (Elliott et al., 1995; Khan & Franks, 2000; Khan et al., 1998; Mackrous & Proteau, 2007). Perhaps very pertinent to the sport of weightlifting in particular, is the notion that practice with anxiety leads to more robust performance under pressure in competition (Lawrence et al., 2014; Oudejans, 2008; Oudejans & Pijpers, 2009). In addition, most of these athletes reported that these anxious states were encountered towards the end of their competition phases of training when they were starting to train close to the loads they were expecting to open their competition lifts with, which suggests they were adopting the recommendations of Lawrence et al (2014) regarding the later timing of anxiety induced practice.

4.4.6 Focus of attention

Whilst no differences were reported in the proportions of practice with different attentional foci, the finding that higher volumes of external focus of attention does support the notion of the accumulations of high practice volumes whilst adopting an external focus of attention. This finding supports the original tenets of the constrained action hypotheses (Wulf, McNevin, & Shea, 2001; see Wulf, 2007, for a review), which mainly asserts that the adoption of an external focus of attention for the benefit of performance accuracy, both in terms of movement outcome (e.g., McNevin & Wulf, 2002; Gabriele Wulf et al., 2001), and movement kinematics (e.g. Lawrence, Gottwald, Khan, & Kramer, 2012; Lohse, Sherwood, & Healy, 2010).

4.4.7 Sources of feedback

Internally derived feedback sources enable athletes to develop an internal representation of the motor programme (van Vliet & Wulf, 2006), and usually stems from a combination of visual, auditory, and proprioceptive sensory sources. This internal representation is proposed to enable the athlete to detect errors about their own performance, from which they can adjust their action plans accordingly. Extrinsic, or augmented feedback is usually provided as part of the coaching process to support the development of intrinsic feedback (van Vliet & Wulf, 2006). This form of feedback can take the form of knowledge of performance, or knowledge of results, the former of which would often take the form of technical feedback from a coach regarding the athletes movement execution (van Vliet & Wulf, 2006), whilst knowledge of results is normally given about the outcome of the specific movement attempt (i.e. success or failed; Schmidt & Lee, 1999; Gabriele Wulf, Shea, & Lewthwaite, 2010). Within the context of the current findings, the stronger internal representation of both the snatch and clean and jerk, perhaps as a result of accumulating higher volumes of weightlifting specific practice, is likely to allow these athletes to rely on proportionately more intrinsically derived feedback.

4.4.8 Prescriptive versus constraints-based coaching

The findings from the current study would seem to suggest that higher proportions and volumes of constraints-based coaching would seem be encouraged for the attainment of high performance in weightlifting. Much like varied practice (see section 3.4.1.6), constraints based coaching is based on ecological psychology and dynamical systems theory (Araújo et al., 2006; Vilar et al., 2012). This perspective describes the performer as a neurobiological system that is constantly interacting with environmental (e.g., lighting, temperature, surfaces, barbell loads, etc), task-based (e.g., force, direction, speed, timing), as well as its own individual (e.g., anthropometric, skeletal muscle strength, mood state, etc) constraints in order to achieve stability in their goal directed activity (e.g., optimal limb coordination and force production throughout the snatch lift). The performer is said to transition between periods of instability, via what is referred to as degeneracy, in order to achieve stability at a higher performance level (Renshaw, Davids, Shuttleworth, & Chow, 2009). Constraints based coaching is based on the deliberate manipulation (either from the coach or the athlete) of either the task, individual, or performer, in order to encourage the transition between period of stability (Renshaw et al., 2010). Most athletes in the current study, when asked to provide examples of their constraints-based coaching, would refer to constraints set by their coach, such as the use of floor markings for their jerk practice, or standing on the edge of a platform to maintain position of the front squat. Some athletes, particularly in the high performing group, had mentioned deliberately practicing with or without wrist straps or knee supports, in order to facilitate their movement.

On the other hand, whilst both groups admitted to their practice containing some degree of prescriptive coaching, the proportions of its inclusion in overall practice were higher in the majority of non-elite group. Prescriptive coaching refers to the direct recommendation of performance solutions that are usually based on extrinsic feedback sources (i.e., knowledge

of performance or results; see section 3.5.2.8). Whilst informative for making specific adjustments to performance, this form of coaching is thought to encourage (1) the performer to become reliant on extrinsic feedback sources, which could potentially distract from encouraging intrinsically derived feedback and may perceive periods of instability as a drop in performance; and (2) the instructions received from prescriptive coaching may form a basis from which to reinvest under conditions of anxiety (Beilock & Carr, 2001; Hardy et al., 1996; Hardy, Mullen, & Martin, 2001). This reinvestment could cause the athlete to overthink these instructions which could constrain what would otherwise be a natural movement. It is proposed in the literature that implicit learning, which would mostly occur through constraints based coaching, would encourage the learner to engage in performance solutions without having any explicit instructions to reinvest with, which ultimately leads to more robust performance under pressure (Hardy et al., 1996; Masters et al., 2008).

4.5 Limitations

These findings should however be taken in the context of the limitations that are underpinned by the study's methodology. The retrospective recall of information, particularly in relation to quantitative data, can be potentially influenced by biases that relate to the developmental perspectives of the athletes. Such biases could result in the overreporting of any information that participants would inherently see as important to their development, and the inverse for any non-relevant information. The next chapter will aim to overcome these limitations by investigating the relevance of some of the findings reported in the current study in a group of youth and junior athletes, who would potentially be undergoing the some of the experiences reported by the senior athletes.

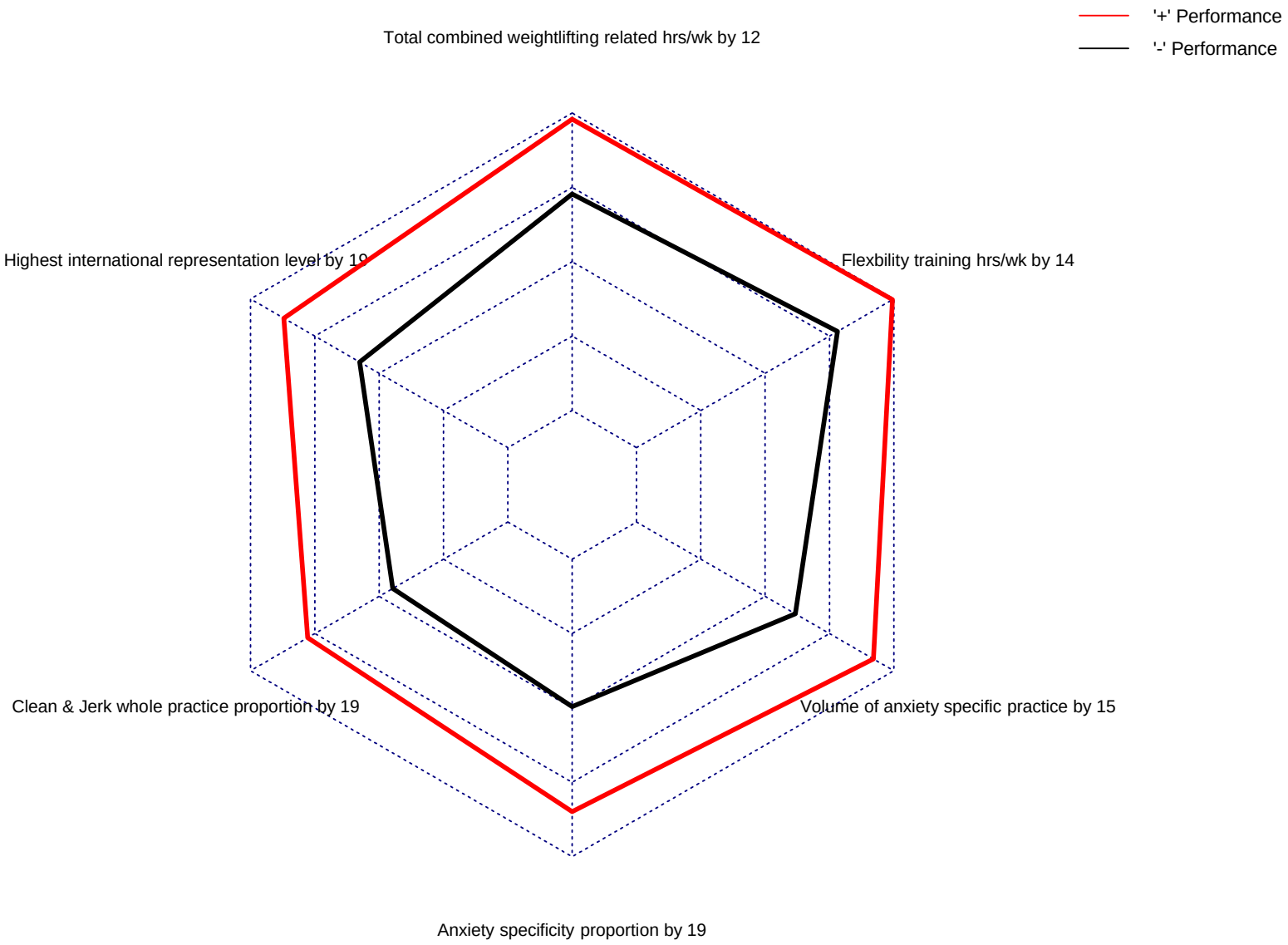

Figure 8. Radar plot depicting the relationships between the performance groups in the summary model

Chapter 4

Practice activities, Psychosocial and Physiological characteristics differentiating performance improvements in Youth and Junior Weightlifters: A longitudinal study

Abstract

Recent studies of talent identification have used retrospective recall methods to explore developmental biographies and/or practice and training histories of athletes who had recently entered retirement (e.g. Güllich et al., 2019; Hardy et al., 2017), which could potentially limit the applicability of these findings to athletes, particularly youth athletes, who may be currently competing. As such, a gap exists for research that explores the key multidisciplinary features in the development of youth athletes using prospective longitudinal research designs. This study therefore aimed to holistically model the development of talent in the sport of Olympic Weightlifting using such a design. We observed the holistic profile of 29 Junior weightlifting athletes longitudinally over a 10-month period, and subsequently classified 6 of the 23 athletes as high performing based on their performances in competitions up to 12 months following the study. This holistic profile was based on a framework of expertise development themes with 5 sections: (1) demographics and family sport participation, (2) anthropometrics and physiological factors, (3) psychosocial profiling (4) sport participation history and weightlifting specific involvement, and (5) weightlifting specific practice activities. Odds ratio calculations uncovered both common and discriminating features in the holistic profile of both performance groups, from which empirically derived logical statements could inform the description of high-performance attainment. A summary model was also produced which selected a critical set of 9 features that classified group membership with 91% average accuracy.

KEYWORDS: talent development; talent identification; expertise development; Olympic weightlifting; machine learning

1. Introduction

The findings from the investigations reported in chapter 3 have indeed supported the conceptualization of elite performance attainment as a complex process resulting from a dynamic interplay of features (Fransen & Güllich, 2019). Specifically, the factors that best differentiated elite senior athletes form their sub elite counterparts stemmed from (1) wider environmental influences such as parental involvement in sport and the size of the homeplace town throughout the athletes early formative years, (2) sampling a variety of sports early in development which accompanied by early flexibility and strength and conditioning training, (3) early challenge in the competitive pathway, specifically on the international stage, and (4) differences in the microstructure of practice in weightlifting throughout from as early as the age of 15 years. However, this study used retrospective recall methods to explore the developmental biographies and practice and training histories of senior athletes, which could potentially limit the applicability of these findings to athletes, particularly youth athletes, who may be currently competing. Moreover, as this study was retrospective in nature, the prospective importance of the athletes physiological and psychosocial profile could not be examined.

As such, a gap in the current thesis exists for research that explores the key multidisciplinary features of expertise development, including physiological and psychosocial profiling, in youth weightlifting athletes using a prospective longitudinal research design. Therefore, the purpose of the current study is to prospectively explore the features that characterise the development of high performance in youth athletes from a single sport using a longitudinal research design. This study will observe the development of a group of youth and junior weightlifting athletes over a 2-year period whilst holistically profiling each athlete on a range of features based on the theoretical framework discussed in chapter 1.

To date, one study has attempted to determine a set of characteristics that were predictive of junior weightlifting performance (Fry et al., 2006). Using a cross-sectional design, Fry and colleagues measured 115 junior weightlifting athletes on a battery of physical and anthropometric variables. Using multiple discriminant function analysis, they found that body mass index, vertical jump, grip strength, and relative torso angle from overhead squat differentiated a low performing group (N = 95) from a high performing group (N = 20) with an 84% classification accuracy. The authors suggested these measures could serve as potential as potential use in future talent identification programmes. However, whilst this study may serve to highlight the potential importance of physical and performance characteristics, its findings are limited to a cross sectional design, and thus doesn't capture any sensitivity of the testing battery to predict future performance, nor does it capture any potential influence of maturation of the physiological characteristics that underpin the variables measures. The current study will therefore seek to incorporate the methodology used by Fry et al into the holistic profiling of youth and junior weightlifting athletes to determine the relative importance of physiological profile on the overall development of the athlete.

As previously mentioned, the current study will also seek to explore the importance of the athletes' psychosocial profile on the development of high performance in weightlifting. As discussed in chapter 1, the psychosocial profile of the athlete includes a combination of personality traits, as well as attitudes and behaviours of the athlete in relation to their sport. A recent seminal investigation on the psychosocial profiles of super elite versus elite British athletes has reported that commonalities existed between the samples with regards to family values, conscientiousness, and commitment to training, whilst differences with regards to their attitudes to training and competition (i.e. a motivation towards the attainment of both

mastery and outcome factors, as well as an inherent need to succeed in their respective sports) and personality traits (i.e. adaptive perfectionism, obsessiveness, and ruthlessness and selfishness) was found (Hardy et al., 2017). These characteristics were likely manifested as a result of experiencing a negative foundational life event which was coupled with the positive experience of finding sport, as well as a career turning point which enhanced their motivation to achieve. The current study will therefore aim to include a form of psychosocial profiling which will operationalise the findings of Hardy et al. in a prospective longitudinal design.

2. Method

2.1 Participants

29 youth and junior weightlifting athletes (21 males, mean age 15.3 ± 1.71; 8 females, mean age 15.8 ± 1.98 years) participated in the current study. All athletes were registered to- and attended regular training at a weightlifting club that was affiliated to the national governing body for weightlifting in Wales. All athletes were nominated by their weightlifting coach to participate in the study before being formally invited to participate by the lead investigators at Bangor University and performance manager for Weightlifting Wales. Invitation to participate in the study was in the form of an information sheet which provided athletes with information about the study's aims and procurers. For athletes under the age of 18 at the time of the start of the study, informed consent was obtained from a parent or legal guardian. Ethical approval for the study was granted by the committee for Ethics at the school of sport, health, and exercise sciences, Bangor university.

2.2 Measures

A total of 648 variables were collected which included a combination of variables that explored the following disciplines: (1) Demographics and family information, (2) athlete physiological profile, (3) athlete psychosocial profile, (4) sporting history and weightlifting

specific involvement, and (5) Weightlifting specific practice. These features are listed in table 11 (see appendices for a specific breakdown of the procedures used).

Table 11. Features used as part of the multidimensional profiling

1. Demographics and familial sport participation ***1.1 Familial sport participation***
Mother involvement in sport, mother experience in weightlifting, father involvement in sport, father experience in weightlifting, same sex sibling, older same sex sibling, same sex sibling experience in weightlifting
1.2 Homeplace throughout development:
Population of longest residing homeplace between 6-12 years, population density of longest residing homeplace between 6-12 years, population of longest residing homeplace between 13-15 years, town population of longest residing homeplace between 13-15 years, times relocated throughout development
1.3 Schooling
Attended sport school between 6-12 years, attended sport school between 13-15 years, school main place for sport participation between 6-12 years, school main place for sport participation between 13-15 year.
1.4 Relative Age
Month of birth (1 = January 12 = December), birth quarter (calendar and school; Q1 = Jan-Mar [calendar], Q1 = Sept – Nov [school]), relative age to nearest aged sibling (in days).
2. Physiology and Anthropometrics (variables were controlled for age and gender): ***2.1 Body Composition:***
BMI, body fat percentage, fat weight (kg), lean weight (kg), dry lean weight, body water percentage, Total Body Water (ltr)
2.2 Body segment ratios:
Upper arm length, forearm length, total arm length, thigh length, tibia length, total leg length, torso length, tibia to height, thigh to height, torso to height, upper arm to height, forearm to height, hand to height, 2D:4D ratio
2.3 Skeletal Muscle Strength:
Left hand grip strength, right hand grip strength, hand grip strength asymmetry, back squat to body weight ratio, front squat to body weight ratio.
2.4 Stretch Shortening Cycle Utilization:
Countermovement jump height, squat jump height , peak power (Sayers equation), peak power (Duncan equation), standing broad jump distance
2.5 Mobility/Trunk Stability:
Body angles during overhead squat test: ankle (relative to horizonal), thigh (relative to horizontal), torso (relative to horizontal), ankle to torso ratio, thigh to ankle ratio, torso to ankle ratio
3. Psychosocial Characteristics (1 to 7-point Likert scale)

Achievement motivation: mastery approach, mastery avoidance, performance approach, performance avoidance. *Athlete behavior:* commitment to training, relative importance of sport, total preparation for competition, relative importance sport, passion for weightlifting: harmonious passion, obsessive passion. *Athlete personality:* conscientiousness, openness to experience, agreeableness, extraversion, emotional stability, ruthlessness and selfishness. Perfectionism: perfectionist strivings, concern over mistakes, perceived parental pressure, perceived coach pressure, doubts about actions, organization.
4. Sport History and Weightlifting Specific Involvement ***4.1 Sport Involvement (between 6 – 12 years):***
Years involved in each of the following sports: athletics, badminton, basketball, boxing, cricket, CrossFit, dance, football, golf, gymnastics, handball, hockey, horse riding, martial arts, motorsports, mountain biking, rounders, rowing, rugby, swimming, tennis, trampoline; years between 6 and 12 years involved in individual sports, team sports, and cgs sports; total number of sports; years between 13 and 15 years involved in individual sports, team sports, and cgs sports; total number of sports.
4.2 Weightlifting specific and related involvement (between ages 6-12):
Number of competitions per year, exposure to competition (hours/year), time spent in competition (hours/year), flexibility/mobility training (hours/week), number of months involved in weightlifting training (hours/week), weightlifting specific practice (hours/week), strength & conditioning training (hours/week).
5. Microstructure of Practice: ***5.1 Sport Involvement (between 6 – 12 years):***
Deliberate practice vs play, mental skills training, vicarious experiences, conveying of information, whole/part practice, constant vs varied practice, specificity of practice, focus of attention, prescriptive versus constraints coaching.

2.3 Procedure

For baseline testing, athletes were invited to one of several testing sessions that took place at various locations across Wales. Testing sessions primarily involved the athletes completing the physical testing battery followed by questionnaires and short, 15 to 20-minute interviews with the second researcher. Testing batteries were mainly completed at the training venue of the athletes. Due to the high volume of data collected on each athlete, testing sessions were spread out over 2-3 testing sessions, usually spanning a period of 2-3 weeks. Testing sessions usually lasted between 45 minutes to 3 hours, depending on the number of athletes attending the testing session, and the number of variables that were being collected on the day. Because of their high sensitivity to time and training stimuli, physiological variables were

collected as a priority for each testing session, and therefore all physical testing batteries were completed at the beginning of each session. The questionnaires and interviews were completed towards the end of each testing session, as the variables collected were somewhat more stable over time. At the end of the baseline testing period, athletes were instructed to participate in their regular training programme as normal for the next 10 months, after which the second round of testing would commence. Testing for the second of testing was scheduled in the same way as the baseline tests were, with testing sessions being spread over a period of 2-3 weeks.

Additionally, data from the athlete's competitive performances was being collected throughout the study and for a further 12 months after the second round of testing. This data was usually being sourced from the Weightlifting Wales (https://www.weightlifting.wales) or British weightlifting (https://britishweightlifting.org) webpages, or in cases for any international competitions, the International Weightlifting Federations (IWF; https://www.iwf.net) or European Weightlifting federation's websites (EWF; https://www.ewfed.com). This data included the recorded snatch, clean & jerk and total weight lifted in each competition, and the rank position for respective weight class. The number of competitions per athlete was also included.

2.4 Data Analysis

2.4.1 Group classification

British percentile calculations were calculated for each athlete's recorded snatch, clean & jerk, and total at each competition. This was performed to establish each athlete's respective score against a population norm. Performance classifications were then assigned to each athlete based on the bottom-up algorithms in chapter 1 that were specific to their age group. Athletes were classified into a high performance and low performance groups that were based on the algorithm's prediction using all performance data up to and including 12 months following the second round of testing. This resulted in a total of 23 athletes that were classified as low

performance (17 males, 6 Females, mean age: 15.1 ± 1.5), and 6 athletes classified as high performance (4 males, 2 females; mean age: 16.6 ± 1.5) by the second round of testing (T2), respectively. These groups were then used as the classification groups for subsequent machine learning analysis.

2.4.2 Machine Learning

Machine learning was implemented in the current study in order to provide a set of rules from which group membership could be best classified. The same four-part methodology was employed in the same study than that used in chapters 1 and 2 namely parameter optimization, calculation of odds ratios, feature selection, followed by classification (see section 7). This analysis was also performed using the rWeka package in R (Hornik et al., 2009), which is an R interface for the WEKA machine learning statistical software package (Witten et al., 2011).

2.4.3 Parameter optimization

Parameter optimization was deployed in the same method as that in chapter 2. This resulted in the creation of 684 new logical attributes that corresponded to the original attributes in the dataset. This resulted in a newly generated dataset containing logical variables, or 'rules', for each original attribute in the dataset.

2.4.4 Odds ratio calculation

As per chapters 2 and 3, odds ratios were calculated for each logical attribute in the data. Odds ratios were adjusted for small samples using the small method, and p values and confidence intervals were calculated using the Fischer's exact method. A logical rule was considered a discriminator for high performance if the p values for the associated odds ratio was below 0.05. The level of importance for each significant attribute were also determined using the methodology outlined in chapter 2 (see figure 5).

Conversely, for any logical rules that did not appear as discriminators, commonalities were determined on the basis that (1) a high proportion of each group (approximately 60% or more) met the condition, and (2) the logical attribute contained theoretical relevance as a commonality. These commonalities amongst the sample could thus be identified as a necessary baseline condition to become involved in weightlifting to begin with.

3. Results

3.1 Demographics and Family

The results will be presented in the order of the sections presented in the previous section. The logical rules for each attribute included in the analysis for demographics and family, along with odds ratios, are presented in table 12.

3.1.1. Commonalities

3.1.1.1 Population Density of longest residing homeplace

A commonality amongst this sample was in relation to the density of the longest residing homeplace between the ages of 6-12 years of age. Moreover, the population density of the longest residing homeplace for 4 of the 6 high performing athletes, and 14 of the 23 low performing athletes was at least 767 pop per km^2.

3.1.1.2 Father involved in sport

A clear commonality amongst this sample of athletes was that most athletes had a father who was involved in sport. Specifically, 15 out of the 23 low performing athletes, and 5 out of the 6 high performing athletes reported that they had their father was involved in either playing or coaching sports themselves. It is also noteworthy to mention the trend towards a commonality for the mother to also be involved in sport.

Table 12. Logical attributes for all common and discriminative features in sections 1 to 5

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
1. Demographics and familial sport participation				
Homeplace throughout development:				

Population of longest residing homeplace between 6 to 12 years over 11,369	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Density of longest residing homeplace between 6 to 12 years over 767 pop/km^2	15/23 (65.2%)	6/6 (100%)	3 (0.36 - 142.56)	-
Familial sport participation				
Father involved in sport	15/23 (65.2%)	5/6 (83.3%)	1.25 (0.27 - 14.71)	-
Schooling				
School main place for sport participation between 6 and 12 years	1/23 (4.3%)	4/6 (66.7%)	14.67 (2.81 - 259.57)	High
2. Sport History and Weightlifting Specific Involvement				
Anthropometrics				
Between T1 and T2:				
Difference in Height between T1 and T2 more than 1.5cm above norm	2/23 (8.7%)	4/6 (66.7%)	9.33 (2.04 - 117.42)	High
Body Segments:				
By T1:				
Tibia length more than 3.79cm above norm	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Total Arm to height ratio above norm	7/23 (30.4%)	6/6 (100%)	12 (1.42 - 576.26)	High
Between T1 and T2:				
Difference in torso length between T1 and T2 more than 1.54cm above norm	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Difference in tibia length between T1 and T2 more than 0.16cm above norm	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Difference in total arm to height ratio between T1 and T2 more than 0.03cm below norm	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Stretch shortening cycle utilization:				
By T1:				
Duncan estimate for countermovement jump peak power more than 225.28W above norm	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Maximum standing broad jump distance more than 11.08cm above norm	4/23 (17.4%)	4/6 (66.7%)	5.07 (1.22 - 49.85)	High
By T2:				
Sayers estimate for countermovement jump peak power more than 317.21W above norm	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Duncan estimate for countermovement jump peak power more than 232.77W above norm	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Maximum countermovement jump height more than 1.48cm above norm	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Maximum squat jump height more than 12.72cm above norm	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	High
Skeletal muscle strength:				
By T1:				
Back Squat to body mass ratio more than 0.67 above norm	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Front Squat to body mass ratio more than 0.03 above norm	8/23 (34.8%)	6/6 (100%)	10 (1.19 - 474.06)	High
By T2:				

Back Squat body mass ratio more than 1.02 above norm	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Front Squat body mass ratio more than 0.48 above norm	2/23 (8.7%)	3/6 (50%)	5.25 (1.19 - 62.13)	Moderate
Between T1 and T2:				
Difference in back squat to body mass ratio between T1 and T2 more than 0.01 above norm	12/23 (52.2%)	0/6 (0%)	0 (0 - 1.4)	Low
Mobility/Trunk Stability:				
By T1:				
OHS torso more than 66.71 degrees	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
3. Psychosocial Characteristics				
Athlete behaviours and attitudes towards training and competition				
Achievement motivation				
Mastery Approach over 6.68	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Mastery Avoidance over 3.56	21/23 (91.3%)	2/6 (33.3%)	0.04 (0.01 - 0.49)	High
Performance Approach over 5.39	4/23 (17.4%)	4/6 (66.7%)	5.07 (1.22 - 49.85)	High
Performance Avoidance over 2.97	18/23 (78.3%)	5/6 (83.3%)	0.66 (0.14 - 8.39)	-
Athlete behaviours and attitudes				
Commitment to training over 4.7	10/23 (43.5%)	6/6 (100%)	7.09 (0.84 - 331.5)	High
Total preparation for competition over 5.15	6/23 (26.1%)	3/6 (50%)	1.82 (0.48 - 15.24)	
Relative importance of sport over 3.55	10/23 (43.5%)	6/6 (100%)	7.09 (0.84 - 331.5)	High
Harmonious Passion over 5.72	2/23 (8.7%)	5/6 (83.3%)	17.5 (3.39 - 293.37)	High
Obsessive Passion over 4.63	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Athlete personality				
Conscientiousness over 5.81	5/23 (21.7%)	5/6 (83.3%)	7.5 (1.6 - 94.94)	High
Openness to Experience over 6.59	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Agreeableness over 2.33	22/23 (95.7%)	6/6 (100%)	0.26 (0.03 - 23.91)	-
Extraversion over 5.21	9/23 (39.1%)	6/6 (100%)	8.4 (1 - 394.78)	High
Emotional Stability over 4.49	15/23 (65.2%)	6/6 (100%)	3 (0.36 - 142.56)	-
Perfectionism:				
P2: Concern over mistakes over 1.09	21/23 (91.3%)	4/6 (66.7%)	0.12 (0.03 - 1.59)	-
P5: Doubts about actions over 2.35	22/23 (95.7%)	0/6 (0%)	0 (0 - 0.14)	High
P6: Organization over 5.61	2/23 (8.7%)	5/6 (83.3%)	17.5 (3.39 - 293.37)	High
4. Sport History and Weightlifting Specific Involvement				
Sport participation throughout development				
Number of sports sampled:				
Sampled at least 1 sport at age 10	20/23 (87%)	6/6 (100%)	0.86 (0.1 - 48.86)	-
Weightlifting related involvement:				
Flexibility/mobility training (hours per week) at:				
Age 10 more than 0.15 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 11 more than 0.17 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 12 more than 0.88 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate

Age 13 more than 0.93 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 14 more than 1.66 hours	0/23 (0%)	4/6 (66.7%)	30.67 (3.45 - 2074.36)	High
Age 15 more than 1.85 hours	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
Strength & Conditioning Training (hours per week):				
Age 9 more than 0.39 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 10 more than 0.49 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 15 more than 2.13 hours	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Weightlifting specific practice (hours per week):				
Age 6 (no minimum)	0/23 (100%)	0/6 (100%)	NA	NA
Age 7 (no minimum)	0/23 (100%)	0/6 (100%)	NA	NA
Age 8 (no minimum)	0/23 (100%)	0/6 (100%)	NA	NA
Total combined flex/mob, strength & conditioning, and weightlifting specific practice (hours per week):				
Age 13 more than 0.78 hours	17/23 (73.9%)	2/6 (33.3%)	0.06 (0.01 - 0.76)	Low
Age 15 more than 9.58 hours	3/23 (13%)	5/6 (83.3%)	12.5 (2.55 - 181.04)	High
Cumulative practice volumes by T1:				
Flexibility/mobility practice over 255.79 hours	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
Strength & Conditioning training over 936.24 hours	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
Weightlifting specific practice over 657.18 hours	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Number of competitions over 8	8/23 (34.8%)	6/6 (100%)	10 (1.19 - 474.06)	High
Competition time over 43.08 hours	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Cumulative practice volumes by T2:				
Flexibility/mobility practice over 195.3 hours	1/23 (4.3%)	4/6 (66.7%)	14.67 (2.81 - 259.57)	High
Strength & Conditioning training over 603.17 hours	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	High
Weightlifting specific practice over 1527.54 hours	2/23 (8.7%)	4/6 (66.7%)	9.33 (2.04 - 117.42)	High
Number of competitions over 10	8/23 (34.8%)	6/6 (100%)	10 (1.19 - 474.06)	High
Competition time over 53.49 hours	3/23 (13%)	5/6 (83.3%)	12.5 (2.55 - 181.04)	High
Cumulative practice volumes between T1 and T2:				
Flexibility/mobility practice over 29.18 hours	5/23 (21.7%)	6/6 (100%)	18 (2.11 - 904.9)	High
Weightlifting specific practice over 392.28 hours	2/23 (8.7%)	3/6 (50%)	5.25 (1.19 - 62.13)	High
Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
5.Microstructure of Practice:				
Deliberate Practice vs Play				
By T1:				
Proportion of deliberate play at least 5%	15/23 (65.2%)	5/6 (83.3%)	1.25 (0.27 - 14.71)	-
Volume of deliberate play more than 313.8 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate

Volume of deliberate practice more than 1078.9 hours	3/23 (13%)	4/6 (66.7%)	6.67 (1.55 - 71.7)	Moderate
By T2:				
Proportion of deliberate play more than 40%	4/23 (17.4%)	0/6 (0%)	0 (0.02 - 7.06)	-
Proportion of deliberate practice more than 60%	19/23 (82.6%)	6/6 (100%)	1.2 (0.14 - 63.58)	-
Volume of deliberate practice more than 1426.51 hours	2/23 (8.7%)	4/6 (66.7%)	9.33 (2.04 - 117.42)	High
Between T1 and T2:				
Volume of deliberate practice between T1 and T2 more than 297.98 hours	2/23 (8.7%)	3/6 (50%)	5.25 (1.19 - 62.13)	Moderate
Mental skills training (hours per week):				
At T1 over 14.2 hours	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
At T2 over 15.7 hours	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Increase between T1 and T2 over 0.98 hours	4/23 (17.4%)	0/6 (0%)	0 (0.02 - 7.06)	
Vicarious Experiences (hours per week):				
By T1 over 4.1 hours	4/23 (17.4%)	4/6 (66.7%)	5.07 (1.22 - 49.85)	High
By T2 over 0.89 hours	13/23 (56.5%)	6/6 (100%)	4.29 (0.51 - 200.54)	-
Information conveyed to the athlete:				
At T1:				
Over 40.49% verbal information	23/23 (100%)	4/6 (66.7%)	0 (0 - 0.94)	Moderate
Over 31.07% demonstration information	3/23 (13%)	5/6 (83.3%)	12.5 (2.55 - 181.04)	High
Over 20.03% video information	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	
At T2:				
Over 50.95% verbal information	23/23 (100%)	1/6 (16.7%)	0 (0 - 0.16)	Moderate
Over 29.69% demonstration information	19/23 (82.6%)	6/6 (100%)	1.2 (0.14 - 63.58)	
Over 18.08% video information	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Between T1 and T2:				
Reduction in verbal information by more than 10 percentage units	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.6)	High
Increase in video information by more than 10.3 percentage unit	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.6)	High
Whole/Part Practice				
For the Snatch:				
At T1:				
Volume of snatch part practice by T1 over 247.8 hours	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Volume of snatch whole practice by T1 over 265.9 hours	0/23 (0%)	4/6 (66.7%)	30.67 (3.45 - 2074.3)	High
At T2:				
Volume of snatch part practice by T2 over 313.2 hours	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.6)	High
Volume of snatch whole practice by T2 more than 327.2 hours	0/23 (0%)	4/6 (66.7%)	30.67 (3.45 - 2074.3)	High
Between T1 and T2:				
Volume of snatch whole practice between T1 and T2 more than 69.6	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.0)	High
For the Clean & Jerk:				

At T1:				
Proportion of clean & jerk practice as parts over 49%	23/23 (100%)	4/6 (66.7%)	0 (0 - 0.94)	Moderate
Proportion of clean & jerk practice as whole movement over 51%	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Volume of clean & jerk part practice by T1 more than 241.2 hours	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	Moderate
Volume of clean & jerk as whole practice more than 206.3 hours	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.6)	Moderate
At T2:				
Proportion of clean & jerk practice as parts over 71%	15/23 (65.2%)	0/6 (0%)	0 (0 - 0.84)	Moderate
Volume of clean & jerk part practice more than 315 hours by T2	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Volume of clean & jerk as whole practice more than 132.3 hours by T2	4/23 (17.4%)	4/6 (66.7%)	5.07 (1.22 - 49.85)	High
Between T1 and T2:				
Volume of clean & jerk whole practice more than 50 hours practice between T1 and T2	2/23 (8.7%)	4/6 (66.7%)	9.33 (2.04 - 117.42)	High
Constant vs Varied Practice				
At T1:				
Constant Practice proportion over 86%	17/23 (73.9%)	1/6 (16.7%)	0.06 (0.01 - 0.76)	Moderate
Varied Practice proportion over 21%	3/23 (13%)	4/6 (66.7%)	6.67 (1.55 - 71.7)	High
Volume of practice with varied practice more than 173.52 hours	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
At T2:				
Varied Practice proportion over 12%	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	Moderate
Volume of practice with varied practice more than 222.39 hours	1/23 (4.3%)	4/6 (66.7%)	14.67 (2.81 - 259.57)	Moderate
Between T1 and T2:				
Volume of varied practice between T1 and T2 more than 135.62 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Specificity of Practice				
Anxiety Specificity:				
By T1:				
Proportion of overall practice over 31.08%	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Volume of Anxiety Specificity training over 443.9 hours	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
By T2:				
Volume of Anxiety Specificity t2 over 556.77	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
Between T1 and T2:				
Accumulated a volume of anxiety specificity practice by more than 112 hours between T1 and T2	1/23 (4.3%)	4/6 (66.7%)	14.67 (2.81 - 259.57)	High
Context Specificity:				
By T1:				
Volume of context specificity training over 162.06 hours	4/23 (17.4%)	4/6 (66.7%)	5.07 (1.22 - 49.85)	High
By T2:				

Volume of context specificity training over 1071.64 hours by T2	2/23 (8.7%)	3/6 (50%)	5.25 (1.19 - 62.13)	High
Focus of Attention				
By T1:				
Volume of practice with internal focus of attention over 281.26 hours by T1	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Volume of practice with external focus of attention over 346.04 hours by T1	2/23 (8.7%)	4/6 (66.7%)	9.33 (2.04 - 117.42)	High
By T2:				
Volume of practice with internal focus of attention over 479.55 hours by T2	5/23 (21.7%)	5/6 (83.3%)	7.5 (1.6 - 94.94)	High
Volume of practice with external focus of attention over 1100.94 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	High
Source of feedback				
By T1:				
Proportion of intrinsic feedback over 21%	2/23 (8.7%)	5/6 (83.3%)	17.5 (3.39 - 293.37)	High
Proportion of extrinsic feedback over 79%	21/23 (91.3%)	1/6 (16.7%)	0.02 (0 - 0.3)	High
By T2:				
Proportion of intrinsic feedback over 25%	3/23 (13%)	5/6 (83.3%)	12.5 (2.55 - 181.04)	High
Proportion of extrinsic feedback over 75%	20/23 (87%)	1/6 (16.7%)	0.02 (0.01 - 0.39)	High
Between T1 and T2:				
Prescriptive versus constraints coaching				
By T1:				
Proportion of practice with prescriptive coaching over 49%	22/23 (95.7%)	2/6 (33.3%)	0.02 (0 - 0.36)	High
Volume of practice with constraints-based coaching over 232.49 hours by T1	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Volume of practice with prescriptive coaching over 1710.24 hours by T1	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	
By T2:				
Proportion of practice with constraints-based coaching over 20%	3/23 (13%)	4/6 (66.7%)	6.67 (1.55 - 71.7)	High
Proportion of practice with prescriptive coaching over 40%	22/23 (95.7%)	2/6 (33.3%)	0.02 (0 - 0.36)	High
Volume of practice with constraints-based coaching over 366.24 hours by T2	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate

3.1.2 Discriminators:

3.1.2.1 Population of longest residing homeplace

A discriminatory feature that appeared in the dataset was in relation to town size, specifically in relation to the population of the community district in which each athlete lived for the longest time throughout the developmental years. Specifically, 5 out of the 6 high

performing athletes lived in a town with a population of more than 11,368, whilst only 6 of the 23 high performing athletes lived in a town this size resulting in an odds ratio of 6.07.

3.1.2.2 School main place for sport participation between ages 6-12 years

The other discriminator that appeared in the dataset in relation to athlete demographics and family sport participation was that the high performing athletes were mainly participating in sport whilst at school. 4 out of the 6 high performing athletes reported that school was the main place for sport participation, whilst only 1 out of the 23 low performing athletes reported the same.

3.2 Physiological profile

3.2.1 Commonalities

Table 12 shows the logical attributes and associates odds ratios for the athlete's physiology and anthropometrics. As can be seen, there were no commonalities amongst the sample of theoretical importance to the current study in this section (the only commonalties that existed were in relation to the knee and hip angle of the overhead squats, which are angles one would expect to achieve by performing the overhead squat).

3.2.2 Discriminators

3.2.2.1 Anthropometrics

Differences in the anthropometrics of the two groups were observed in this sample. These differences were observed at a combination of the cross sectional (by T1), and longitudinal (between T1 and T2) levels. Specifically, at T1, 2 of the high performing athletes had a tibia length more than 3.8cm longer than the expected value for their respective age and gender, whilst none of the 23 lower performing athletes reported this. In addition, all 6 of the high performing athletes had a total arm length to height ratio above that expected, whereas 7 of the 23 low performing athletes reported this ratio. Between T1 and T2, 4 out of 6 high performing athletes recorded growth in height more than 1.5cm above the normative value for

their age and gender, whilst only 2 of the 23 low performing athletes reported this. This was accompanied by respective increases in both the torso length (>1.54cm) and tibia length (>0.16cm) for 3/6 and 5/6 in high performing athletes, whilst only 1/23 and 6/23 of the low performing athletes demonstrated these respective increases in segment lengths.

3.2.2.2 Stretch shortening cycle utilization

Differences in the diagnostic measurements for stretch shortening cycle utilization were observed between the groups at the cross-sectional level (by both T1 and T2) only. At T1, 4 out of the 6 high performing athletes achieved a standing broad jump distance more than 11cm above their expected value for achieve and gender, whilst only 4 of the lower performing athletes achieved this. Similar observations were also observed for the peak power estimate of the countermovement jump using the Duncan estimation formula (a formula derived from a population of English school children that controls for age and gender; (Duncan, Hankey, & Nevill, 2013). Specifically, 5/6 high performing athletes produced peak power estimates 225W above the normative at T1, whilst only 6/23 low performing athletes produced this.

By T2, discrimination occurred between the groups for the countermovement jump height and squat jump height, as well as estimates for CMJ peak power using both the Duncan and Sayers (a more commonly used method; Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999) estimation methods. 5 out of 6 high performing athletes produced CMJ heights of 1.48cm above the normative value for age and gender, which resulted in peak power estimates on the countermovement jump of more than 233W (Duncan) and 312W (Sayers) above the normative value, with only 6 of the 23 low performing athletes achieving this. For the squat jump height, 2 of the high performing athletes jumped 12.72cm above the normative value for age and gender, whilst 0 of the low performing athletes reported this.

3.2.2.3 Maximum Dynamic Strength

An important discriminator in the physiological dataset was the both the back and front squat to body mass ratio. This attribute produced significant odds ratios at both the cross sectional (both T1 and T2) and longitudinal (between T1 and T2) level. Specifically, all 6 high performing athletes reported having a front squat to body mass ratio that was above the normative ratio for age and gender by T1. This was not as common amongst the low performing athletes, in which only 8 out of the 23 athletes reported this. Additionally, 3 of the 6 high performing athletes reported a back squat to body mass ratio that was 0.67 units above the normative ratio for age and gender, whilst only 1 of the 23 low performing athletes reported this.

A similar pattern was observed for T2, with 2/6 and 3/6 high performing athletes achieving respective back squat and front squat to body mass ratios of 1.02 and 0.48 above the normative value, with just 0/23 and 2/23 of the low performing cohort achieving this. This result is unsurprising, given the high correlation between maximum dynamic strength and weightlifting performance, particularly in relation to the back squat (r = 0.86, Beckham et al., 2013). This also suggest that an important prerequisite for development of elite weightlifting performance is the development of the maximum back and front squat. This is also evidenced by the odds ratios reported in table 12, as the attainment of a maximum back squat to body mass ratio 0.7 units about the expected increases the likelihood of high performance by approximately 8-folds.

Between T1 and T2, however, an opposite trend emerged in the back squat to body mass ratio data. 12 of the 23 low performing athletes reported increases of more than 0.01 units above the normative value for age and gender, whilst 0 of the 6 high performing athletes reported this. At first glance, this finding would seem to suggest that improvements in back squat to body mass ratio is indicative of a lower performance level in weightlifting. However, it is likely that due to the higher performing group having a higher back squat to body mass

ratio to begin with, that improvements beyond that expected for age and gender were less likely to occur. Conversely, lower back squat to body mass ratio in the low performing group at the start of the study would encourage bigger improvements between T1 and T2.

3.2.2.4 Trunk Stability

Another important discriminator for high performance is in relation to the stability and control of the trunk in the overhead squat test. Odds ratios for this attribute were significant at the cross-sectional level (T1 only). Specifically, 2 out of the 6 high performing athletes were reported to have a torso angle (relative to horizontal) of 67 degrees or more, whilst 0 out of the 23 of the low performing athletes could manage to achieve this. This suggests that the ability to achieve a position in the squat which allows the angle of the torso to be open enough to support the position of the barbell will support a balanced weight distribution throughout the squat. This could also perhaps be linked to the longer tibia lengths reported above.

3.3 Psychosocial Profile

3.3.1 Commonalities

3.3.1.1 Athlete Personality:

3.3.1.1.1 Agreeableness

A commonality amongst the weightlifting cohort that related to athlete personality is the trait characteristic agreeableness. This trait is one of the big 5 personality characteristics and refers to the degree with which a personality is able to agree with their surroundings. Those high in agreeable tend to be higher in compliance, trust, and straightforwardness (Matsumoto & Juang, 2004). 22 of the 23 low performing athletes, and 6 out of 6 high performing athletes scored above 2.33 for agreeableness, thereby suggesting the personality trait agreeableness to be a general feature of participation in weightlifting.

3.3.1.1.2 Emotional Stability

Another personality-based commonality amongst the weightlifting sample is also a big five personality trait: emotional stability. This personality trait refers to the tendency to remain stable and balanced emotionally in the face of a wide variety of situations. Individuals low in emotional stability tend to exhibit forms of neuroticism under conditions of threat or challenge (Thompson, 2008). 15 out of the 23 low performing athletes reported an emotional stability score of 4.5 or above, as did 6 out of 6 high performing athletes. Unsurprisingly, the personality trait appears to be a necessary characteristic for weightlifting participation, as the ability to maintain emotional stability under pressure is also a necessary determinant of successful weightlifting performance.

3.3.1.2 Attitudes towards training and competition:

3.3.1.2.1 Performance avoidance

A number of common and discriminative features were observed in the current study (see table 12). In the first commonality, 5 out of the 6 high performing athletes, and 18 out of the 23 low performing athletes scored above 3 for the performance avoidance construct in the achievement goal questionnaire. Questions in this construct included items such as 'I just want to avoid performing worse than others', which refers to a degree of weightlifting involvement that is motivated by a socially oriented assessment of performance, particularly in relation to an inferior assessment of themselves in relation to other performers. All athletes scoring higher than 3 on this construct suggests that a prerequisite of weightlifting involvement includes a motivation that is oriented towards the avoidance of performance related comparisons.

3.3.1.2.2 Concern over mistakes

The degree with which athletes showed concern over their mistakes also appeared to be a commonality amongst the weightlifting cohort. 4 out of the 6 high performing athletes, and 21/23 low performing athletes scored above 1.1 for this attribute. The relatively low threshold parameter that was selected for this logical attribute (i.e., 1.1 out of 7) suggests that

there is a minimum amount of concern over mistakes that ought to be present in order to be involved in weightlifting, and that a very low score on this attribute (i.e., lower than 1), would suggest that an attitude towards training that expresses too little concern over mistakes would not be a desired attribute for weightlifting involvement to begin with.

3.3.2 Discriminators

3.3.2.1 Attitude towards training and competition:

3.3.2.1.1 Mastery Approach

There were also some key discriminators in the psychosocial profile of the weightlifting sample. The first discriminatory variable refers to the mastery-oriented achievement motivation construct, termed mastery approach. Three out of the 6 high performing athletes rated their mastery approach above 6.68 (corresponding to a rating of 'very much like me'), whereas only 1 out of the 23 low performing athletes rated themselves this highly. This suggests that mastery approach is positively associated with attainment of high performance in weightlifting, especially given the comparatively high odds ratio of 8.25 for this construct.

3.3.2.1.2 Mastery Avoidance

In addition to mastery approach, mastery avoidance has also been identified as a discriminating feature in the psychosocial profile of high performing weightlifting athletes in comparison with low performing athletes. However, in contrast to mastery approach, a higher score for mastery avoidance was more characteristic of the low performing group, as 21 of the 23 athletes scored 3.56 or above for mastery avoidance, whereas only 2 of the 6 high performing athletes scored above this amount. Items in the questionnaire targeting mastery avoidance included 'I'm often concerned that I may not perform as well as I can perform', which refers to the motivation for training that is driven by the avoidance of self-referenced incompetence.

3.3.2.1.3 Performance Approach

Another motivational construct that is established as a discriminating feature in this study refers to the ego-oriented approach motivation construct, performance approach. This construct refers to the motivation to achieve competence at a task that is based on a normative standard. Individuals high in this construct tend to be highly motivated to demonstrate competence by outperforming others. In the current sample, 4 out of the 6 high performing athletes rated their performance approach as 5.39 or above, whilst only 4 out of the 23 low performing athletes reported this. Taken together with the odds ratio of 5.07, this suggests the importance of performance approach motivation in the context of high-performance attainment in weightlifting.

3.3.2.1.5 Commitment to training

Another athlete behaviour based psychosocial construct that discriminated between the two groups is in relation to athlete's commitment to training. This construct formed part of an earlier iteration of the athlete development formulation survey (ADFS; Langham-Walsh et al, in preparation) which aimed to target the athlete's degree of motivation towards attending and completing all of the necessary training for competitions. Items in this section aimed to target athletes' attitudes towards completing high volumes of training, such as "I try to make my training sessions as productive as possible" and "I try to fit in as much training into my week as possible". All 6 of the high performing athletes reported a rating for commitment to training as 4.7 or above, whereas only 10 of the 23 low performing cohort reported this score.

3.3.2.1.6 Relative importance of sport

The next construct refers to the importance with which athletes place their involvement in sport in relation to other potential life choices and commitments. A high relative importance of sport suggests that an individual perceives their involvement in sport as more important than other life choices, such as personal relationships and other potential life choices. For this section, athletes were asked to rate how best their relationship with weightlifting described them using the importance of others in the self-scale (Aron, Aron, & Smollan, 1992). This scale was represented by two circles labelled “Me” and “Weightlifting”, which varied in degrees of overlap with each other from no overlap to a full overlap of the circles separated by 6 images of increasing overlap between them. This scale was converted to numeric values such that 7 represented the full overlap (i.e., high relative importance), and 1 represented no overlap in the circles (i.e., low relative importance). In the current study, all 6 of the high performing athletes reported a score for relative importance of sport as 3.5 or above, whereas 10 of the 23 low performing athletes reported this score. This produced an odds ratio of 7 for this logical attribute, which would therefore suggest that a higher degree of relative importance of weightlifting serves to encourage the attainment of high performance in weightlifting, particularly in combination with other attitudes that have been recognised in this section.

3.3.2.2 Athlete personality

3.3.2.2.1 Conscientiousness

In addition to attitudes towards training and behaviour, there were also some personality constructs which differentiated the psychosocial profiles of the groups. The first is in relation to the big five personality characteristic, conscientiousness. Conscientiousness describes the ability to control impulse-related behaviours in order to preserve task- and goal-directed behaviour (John & Srivastava, 1999). Only 5 of the 23 low performing athletes reported a score above 5.8 for conscientiousness, whereas 5 out of 6 athletes reported a score

above 5.8 for conscientiousness. An odds ratio of 7.5 also suggests that this feature is a critical component for the attainment of high performance in weightlifting.

3.3.2.2.2 Extraversion

Another one of the big five personality traits that's have appeared as a discriminating feature in this sample was extraversion. Specifically, all 6 of the high performing athletes reported a score for extraversion of 5.2 or above, whilst only 9 out of the 23 low performing athletes reported this.

3.3.2.2.3 Openness to Experience

Another big five personality construct which was identified as a discriminating feature was openness to experience. Two of the 6 high performing athletes reported a score for openness to experience above 6.6, whereas 0 of the high performing athletes demonstrated a performance score above 6.6. A significant odds ratio of 9.02 also suggests this features high importance for success attainment in weightlifting.

3.3.2.2.4 Organization

Another psychosocial feature that was found to be a discriminating feature in the current study was organization. Organization stems from an adaptive form of perfectionism and is described as tendencies to establish and implement routines or plans that guide their behaviour prior to and during competition. Items used in the questionnaire for this construct were 'I follow pre-planned steps to prepare myself for competition'. Five of the 6 high performing athletes reported a score for organization of 5.61 or above, whilst only 2 of the 23 low performing athletes reported the same score. This finding confirms the importance of athletes to be meticulous in their preparation for competition, particularly with regards to their pre-planned routines, in order to attain high levels of performance.

3.3.2.2.5 Doubts about actions

Another construct of perfectionism that appeared to be a discriminatory feature in this study was doubts about actions. Twenty two of the 23 athletes in the low performing group reported a score of 2.35 or above for doubts about actions, whereas none of the 6 high performing athletes reported this score, which resulted in a significant odds ratio of 0. This finding therefore suggests that doubts about actions would be a highly undesired characteristic for the attainment of high performance in weightlifting. This finding seems rather intuitive in the context of weightlifting, since the margin for error during competitions in particular are small, and as such any overriding concerns or doubts about one's own action could ultimately result in negative performance consequences.

3.3.2.2.6 Harmonious and Obsessive Passion

Another discriminatory feature was in relation to the amount of harmonious and obsessive passion that was reported by each athlete. 5 of the 6 high performing athletes reported a score for harmonious passion above 5.7, as opposed to only 2 out of the 23 low performing cohort which reported the same score. This was in addition to 4 out of the 23 low performing athletes reporting themselves as scoring above 4.6 on the obsessive passion construct, in comparison to 5 out of 6 of the high performing athletes reporting this score. This result appears to suggest an influence of passion as whole on the attainment of high performance in this sample, as both forms of passion appeared to be a dominant feature in the high-performance sample.

3.4 Sporting history and weightlifting specific involvement

3.4.1 Commonalities

3.4.1.1 Sport participation throughout sampling years

An important prerequisite for weightlifting participation as a whole was to be involved in at least 1 sport by the age of 10. Six out of the six high performing athletes, and 20 out of the 23 low performing athletes had reported that they were participating in at least one sport by the age of 10. This finding is similar to the findings for the senior athletes reported in chapter 1, although the findings in that study were reported from as early as age 6.

3.4.1.2 Weightlifting specific involvement

Neither of the groups recalled any weightlifting specific involvement during their early formative years (ages 6 to 9). Additionally, engagement in a combination of weightlifting specific training, general strength and conditioning, as well as flexibility and mobility training for extensive periods (more than 1 hour per week) did not appear to be reported in the majority of the sample up until age 11.

3.4.2 Discriminators

3.4.2.1 Weightlifting related involvement

Whilst the engagement in high volumes of weightlifting related training throughout the sampling years was not a prerequisite for weightlifting participation, a small degree of involvement in weightlifting related training from an early age did appear to be a discriminator for weightlifting performance. Specifically, 2 out of the 6 high performing athletes were involved in at least 25 minutes of strength and conditioning based activity from as early as 9 years of age, whilst none of the 23 low performing athletes were involved in any strength and conditioning related activity at this age. Additionally, 2 out of 6 high performing athletes were engaged in at least 25 minutes of flexibility and mobility related activity from as early as 10 years of age, whilst none of the low performing were. There was also evidence for a progressive

increase in volume of flexibility and mobility training with age, as 2 out of the 6 high performing athletes were completing 30 minutes of flexibility and mobility training per week by the ages of 12 and 13, with this increasing to at least 50 minutes per week by the age of 12, and more than 1 hour and 45 minutes by age 15. None of the low performing group were completing this volume of flexibility and mobility training by these ages. This early exposure to weightlifting related training was also reflected in the total volume of practice in each of the weightlifting related domains the high performing groups had accumulated up until the beginning of the study as well between T1 and T2. Specifically, 3 out of the 6 high performing athletes had accumulated at least 256 hours of flexibility and mobility related training prior to T1. Additionally, all 6 performing athletes had amassed at least 30 hours of flexibility and mobility training during the 10-month period between T1 and T2. To put this into perspective, this amounted to a minimum of 44 minutes of flexibility and mobility training per week. Again, this was not as apparent in the low performing group, as just 5 of the 23 athletes had accumulated this volume of flexibility training. The trend was similar for the volume of strength and conditioning practice at the cross-sectional level, as 3 out of the 6 high performing athletes managed to acquire at least 936 hours of general strength and conditioning related training by T1, whilst 0 of the 23 low performing athletes had acquired this. These findings are very similar in context to that reported in chapter 3. Early weightlifting related exposure, in the form of flexibility and strength and conditioning activities, does therefore appear to be an important characteristic for developing the necessary strength and flexibility adaptations for subsequent weightlifting performance.

3.4.2.2 Weightlifting specific involvement

For weightlifting specific involvement, evidence existed at both the cross-sectional and longitudinal level that the total volume of practice was important discriminator of performance. By T1, 3 out of 6 high performing athletes had accumulated a volume of 657 hours of weightlifting specific practice, whilst only 4 of the 23 low performing athletes had acquired this volume. By T2, this volume had increased to 1527 hours, with 4/6 high performing, and just 2/23 low performing athletes acquiring this volume. In addition, 3 out of the 6 high performing athletes had acquired more than 392 hours of weightlifting specific practice or more in the 10-month period between T1 and T2, with only 2 out of the 23 low performing athletes managing to acquire this. This amounted to approximately 9 hours and 50 minutes of weightlifting specific practice per week.

The high performing group were also more exposed to competitions prior to the baseline testing, with all 6 of the high performing group having competed in at least 9 competitions prior to the baseline testing. Only 8 of the 23 low performing athletes had managed to compete in at least 9 competitions. This had increased to 10 competitions by T2, with the same respective athletes acquiring this amount. Interestingly, when asked to estimate the total volume of time spent in a competitive environment, 5 out of the 6 high performing athletes reported to have been exposed to 43 and 53 hours of competition time or more by T1 and T2 respectively, and only 4 out of the 23 low performing athletes completing this. This estimate included exposure to the competition environment itself, such as weighing in on the morning of a competition, managing the food intake between the weigh in and competition time, warming up for the competition, as well as competing in the competition itself.

3.4.2.3 Investment in weightlifting

An interesting finding was observed in relation to the combined volume of weightlifting related and weightlifting specific practice between the ages of 13 to 15. Specifically, at 13 years of age, a significantly large proportion of the low performing athletes were completing at least 50 minutes of weightlifting specific or related practice per week, whilst only 2 of the high performing athletes were completing this volume. The relationship had reversed by age 15, with 5 of the 6 high performing athletes completing volumes of 9.58 hours per week, and only 3 of the 23 low performing athletes reporting this. This finding is potentially indicative of a transition between sampling to specialization in the high performing group, with the onset of high-volume training occurring at 15 years of age. On the other hand, the low performing group did not demonstrate this transition into investment, as a large proportion of this group did not demonstrate increases in training volumes by this age.

3.5 Microstructure of practice

3.5.1 Commonalities

3.5.1.1 Deliberate Play versus Practice

A commonality that existed amongst the sample is in relation to the proportions of deliberate practice and play that were reported. For the deliberate play proportions, 5 out of the 6-high performing, and 15 of the 23 low performing athletes reported that at least 5% of their weightlifting specific involvement prior to T1 was classified as deliberate play. This would suggest that all athletes in the sample experienced a part of their training that was developmentally free from focus, enjoyable, and not inherently focused on the development of performance. This finding is not too surprising, given that the sample consisted of youth and junior athletes, and as such many of these athletes were still adjusting to the demands of the sport.

However, the majority of practice for both groups throughout the study was reported to meet the tenets of deliberate practice, such that it was effortful, focused, and goal directed.

Nineteen of the 23 low performing athletes, and all 6 high performing athletes reported that more than 60% of their practice by T2 was deliberate practice. The relatively low parameter that was selected was likely attributable to the 4 low performing athletes who reported that more than 40% of their practice at T2 was deliberate play. All of these athletes reported this because of either an injury sustained throughout the period of the study, or not qualifying for any national level competitions, which discouraged them from sustaining high proportions of deliberate practice. Nonetheless, the majority of both performance groups were able to sustain high proportions of deliberate practice throughout the study, which further highlights the importance of engagement in deliberate practice as a prerequisite for participation in the sport.

3.5.1.2 Vicarious Experiences

Another commonality amongst this sample of youth and junior athletes was in relation to the vicarious experiences reported by both groups. Specifically, all 6 of the high performing athletes, and 13 of the 23 low performing athletes reported undergoing some form of vicarious experience for at least 50 minutes per week. This suggests that weightlifting involvement on the whole promotes the engagement in weightlifting related vicarious experiences. As most weightlifting clubs often have athletes of different levels of experience that often train at the same time, many of the athletes in this sample would have undergone some form of vicarious experience whilst observing other, often more experienced, athletes train in the same environment as them. It is therefore likely that weightlifting involvement allows for a baseline level of vicarious experiences of approximately 50 minutes per week. As will be discussed in the discriminatory features section, higher volumes of weightlifting related vicarious experiences promoted higher weightlifting performance.

3.5.1.3 Whole versus Part Practice

Elements of the proportions of whole and part practice for the snatch as commonalties in this sample. Evidence for this commonality existed at the cross-sectional level. More specifically, all 6 of the high-performance athletes, and 17 of the 23 low performing athletes reported that at least 30% of their practice for the snatch at T2 consisted of whole practice (that is, practicing the execution of the whole movement). This would suggest that at least a third of the practice of the snatch should be practiced as a whole movement in order to promote the motor systems to organise throughout the whole movement (Naylor & Briggs, 1963). For part practice for the snatch, 6 out of the 6 high performing, and 17 out of the 23 low performing athletes highlighted that they practiced the snatch in no more than 4 parts, which suggests that breaking the snatch down any further wouldn't be too necessary for the development of the snatch motor programme. In terms of volume, part practice for the snatch typically amounted to approximately 50 or more hours of practice between T1 and T2, as 14 of the 23-low performing, and 5 out of 6 high performing athletes had amassed at least this volume of practice.

3.5.2 Discriminators

3.5.2.1 Volume of Mental Skills Training

The volume of mental skills training that was reported appeared as a discriminatory feature in this sample. As mentioned in chapter 3, mental skills training referred to the amount of time during a typical week which was spent mentally rehearsing their own performance routines (usually through imagery) or reflecting on past training and competition experiences. Three out the 6 high performing athletes reported undergoing mental skills training for at least 14 hours per week (i.e., equivalent to 2 hours per day) at both T1 and T2, whilst only 1 of the 23 high performing athletes reported completing this amount. Like the findings reported in chapter 2, it is likely that the greater volume of mental skills training reported in the high-

performance sample promoted a higher level of mental preparation in these athletes both in relation to training and competition.

3.5.2.2 Vicarious Experiences

The volume of vicarious experiences reported also appeared as a discriminating feature in the sample. Specifically, 4 out of the 6 high performing athletes, and just 4 out of the 23 low performing athletes reported completing at least 4 hours and 15 minutes of vicarious experiences per week by T1. As mentioned in section 3.5.1.2, vicarious experiences referred to the experiences undergone as a result of observing other athletes prepare for and compete in training and competition. Given that a baseline amount of vicarious experiences of 53 minutes was established as a commonality amongst the cohort by T2, it is likely that a higher volume of vicarious experiences would be required in order to achieve high performance.

It is likely that this experience could have taken the form of watching more experienced athletes train and compete at the same venue in which the athlete trains. However, given the relatively high volume of vicarious experiences reported, it is likely that these experiences could have taken the form of additional time spent outside of typical training time experience athletes perform vicariously. This could have been through watching weightlifting competitions live or televised, or through conversations with friends or siblings involved in weightlifting.

3.5.2.3 Conveying of Information

The proportion of the types of information that is conveyed to the athlete appeared to be a discriminating feature in this dataset at both the cross sectional and longitudinal level. Specifically, all 23 of the low performing athletes reported that the proportion of verbal information that is conveyed to them was at least 50% by the second testing phase in the study,

whilst only 1 of the 6 high performing athletes reported this. Moreover, 3 of the 6 high performing athletes reported reductions in the proportion of verbal instructions received between T1 and T2 of at least 10 or more percentage units, whilst 0 of the 23 low performing athletes reported this. This suggests that the high performing group were receiving proportionately less verbal instruction between the two testing phases.

In relation to the proportion of video information, 5 of the 6 high performing athletes were receiving at least 18% of their overall information from video sources by T2, whilst only 6 of the 23 low performing athletes were reporting this. Additionally, 3 of the 6 high performing athletes reported increases in the proportion of video information received between T1 and T2, whilst 0 of the 23 low performing athletes reported these increases. This could potentially suggest that the high performing athletes were becoming increasingly more encouraged to attain information from video sources, which would encourage them to extract their own cues and subsequently generate their own feedback from these forms of information. This could perhaps be more indicative of an associative phase of learning, in which consolidation of information from earlier phases of learning occurs before shifting towards autonomous learning (Fitts & Posner, 1967).

Lastly, 5 of the 6 high performing athletes reported that at least 31% of the proportion of information they received at T1 was in the form of a demonstration, whilst only 6 of the 23 low performing athletes reported this. Taken together with the findings for the verbal and video instruction at T1, it appears that the higher performing group received proportionately more visual information than did the low performing group, whilst the low performing group received proportionately more verbal information.

3.5.2.4 Whole versus Part Practice

The proportions of whole versus part practice in the clean & jerk, as well as the volumes of whole practice for the snatch, whole and part practice for the clean & jerk were identified as discriminating features in the sample. This evidence existed predominantly at the cross-sectional level, but some longitudinal evidence also existed for the reported practice volumes. Specifically, at T1, the proportion of part practice for the clean & jerk in all 23 low performing athletes was at least 50% of their overall clean & jerk practice, whilst 4 out of 6 high performing athletes reported this. Conversely, the remaining 2 out of 6 high performing athletes reported that they practiced the clean and jerk as a whole movement for the majority (more than 51%) of their clean and jerk practice. At T2, 15 of the 23 low performing athletes reported that their part practice for the clean and jerk formed more than 71% of their overall clean and jerk practice, whilst none of the high performing athletes reported this. There were no significant changes in practice proportions between T1 and T2. This finding highlights the importance of practicing the clean and jerk as a whole movement for a significant portion of practice in order to attain high performance.

For whole and part practice volumes, 5 of the 6 high performing athletes reported completing at least 248 hours of snatch part practice by T1, whilst only 4 of the 23 low performing athletes reported this. Similar volumes were reported for the snatch whole practice, with 4 of the 6-high performing, and none of the 23 low performing accumulated a volume of 266 practice hours by T1. By T2, these volumes were reported as 313 hours for snatch part practice, and 327 hours for snatch whole practice for the same athletes. Between T1 and T2, 3 of the high performing athletes had amassed more than 70 hours of snatch whole practice, whilst only 1 of the 23 low performing athletes attained this.

For the clean and jerk practice volumes, similar relationships were observed. Specifically, by T1, the same proportion of athletes who attained the reported snatch volumes at T1 had accumulated a total of 241 and 206 hours of part and whole practice for the clean

and jerk, respectively. By T2, these volumes were reported as 315 hours for part practice, and 132 hours for whole practice, with 5 out of 6 high performing, and 4 out of 23 low performing athletes attaining these volumes. Between T1 and T2, 4 out of the 6-high performing, and 2 out of the 23 low performing had practiced the clean and jerk as a whole movement for more than 50 hours, which amounts to more than 1 hour and 15 minutes of clean and jerk practice each week.

3.5.2.5 Constant versus Varied Practice

Another important discriminating feature in this sample appeared to be the proportion of time spent practicing with an environment that induced variable practice conditions throughout the study. Evidence for this finding existed mainly at the cross-sectional level, although longitudinal differences in varied practice volumes were also reported. More specifically, 17 of the 23 low performing athletes reported that more than 86% of their overall practice conditions at T1 were kept constant, whilst just 1 of the 6 low performing athletes reported this. Conversely, 4 out of 6 high performing, and 3 out of 23 low performing athletes reported varied practice conditions of more than 21% of their overall practice. This was also reflected in the volume of accumulated varied practice by T1, as 3 of the six high performing athletes had accumulated at least 173.5 hours of varied practice training, whilst only 1 of the 23 of low performing athletes reported this. By T2, this volume was reported to be as high as 222 hours of varied practice, with 4 of the 23-high performing, and 1 of the 23 low performing athletes acquiring this volume. The varied practice proportions at T2 were also differentiated between the samples, as 5 of the 6-high performing, and 6 of the 23 low performing athletes reported varied practice condition proportions of more than 12%. Between T1 and T2, 2 of the 6 high performing had amassed a total of 135 hours of varied practice conditions, whilst 0 of

the 23 low performing athletes reported this. This equated to approximately 3 hours and 25 minutes of varied practice each week.

3.5.2.6 Specificity of practice

The proportions of practice conditions that matched the specific demands of competition conditions, as well as practice volumes, also emerged as discriminating features in this sample. Evidence for this discriminating feature emerged mainly from cross sectional comparisons, although some longitudinal evidence for volumes of anxiety specificity practice also emerged. More specifically, by T1, proportions of practice with anxiety specific conditions were reported to be more than 31% in 3 of the 6 high performing athletes, whilst only 1 of the low performing athletes reported this. This amounted to approximately 444 hours of anxiety specific practice by T1 in the same 3 out of 6 high performing athletes, with none of the 23 low performing athletes reporting this. By T2, the volumes of anxiety specific practice were reported to be more than 557 hours in 3 of the 6 high performing athletes, whilst 0 of the high performing athletes reported these volumes. Between T1 and T2, 4 out of 6 high performing, and just 1 of the 23 low performing had acquired more than 112 hours of anxiety specific practice, which amounted to approximately 2 hours and 45 minutes of anxiety specific practice per week.

For context specificity practice, significant differences were reported in the volume of context specificity practice by T1, as 4 out of the 6-high performing, and 4 of the 23 low performing athletes reported that they had amassed more than 162 hours of context specific practice. By T2, the volumes of context specific practice were reported to be more than 1072 hours of practice in 3 out of the 6 high performing and 2 of the 23 low performing athletes. Interestingly, when asked to provide a rating of how difficult they found these experiences at

T2, 2 of the high performing athletes reported scores of less than 2 out of 10 (i.e., equivalent to very easy), whilst 0/23 low performing athletes reported this.

3.5.2.7 Focus of attention

Although no differences in the proportions of attentional foci adopted during practice were observed between the groups, the groups differed on the volumes of practice using both internal (i.e., body related) and external (i.e., outside of body related) attentional foci. These differences were observed at the cross-sectional level. By T1, 5 of the 6 and 4 of the 6 high performing athletes had respectively amassed 281 and 346 hours of practice with an internal- and external-focus of attentional, whilst just 4 of the 23 low performing and 2 of the 23 reported these respective practice volumes. Additionally, by T2, 5 of the 6 high performing athletes and just 5 of the 23 low performing athletes had acquired more than 479 hours of practice with an internal focus of attention, and 3 of the 6 high performing athletes reported volumes of more than 498 hours of practice with an external focus of attention, whilst just 2 of the 23 low performing athletes reported this.

3.5.2.8 Sources of feedback

The proportions of externally versus internally derived feedback also positively discriminated between the groups. Evidence for this finding was solely derived from cross sectional observations. By T1, 5 out of 6 high performing athletes reported that more than 21% of their feedback was typically derived from intrinsic (i.e., self-generated sources), whilst 2 of the 23 low performing athletes reported this. Conversely, the remaining 21 low performing and 1 high performing athlete reported that at least 81% of their feedback was mainly derived from external sources, such as feedback regarding knowledge of performance and knowledge of results, which was predominantly from their coach. By T2, the proportion of intrinsic feedback

was reported to be more than 25%, with 5 of the 6-high performing, and 3 of the 23 low performing athletes reporting this proportion. The remaining 20 low performing and 1 high performing athlete reported extrinsic feedback sources of more than 75%.

3.5.2.9 Prescriptive versus constraints-based coaching

The key discriminating feature in relation to coaching and the type of coaching conveyed to each athlete was the proportions and volumes of prescriptive and constraints-based coaching. Like sources of feedback, evidence for this finding was mainly at the cross-sectional level, although longitudinal evidence existed for the volumes of constraints-based coaching. Specifically, by T1, 22 of the 23 low performing athletes reported that at least 49% of their coaching was prescriptive at both T1 and T2, whilst only 2 of the 6 high performing athletes reported this. In addition, 2 of the high performing athletes reported volumes of practice with constraints-based coaching of at least 233 hours, whilst 0 of the 23 low performing athletes had acquired this. By T2, 22 of the 23 low performing athletes reported proportions of over 40% of their typical practice routines, whilst only 2 of the 6 high performing athletes reported this. For constraints-based coaching, 4 of the 6-high performing, and just 3 of the 23 low performing athletes reported practice proportions of more than 30% by T2. Of the 4 high performing athletes reporting this, 2 of these athletes had amassed volumes of constraints-based practice of more than 366 hours. Between T1 and T2, 3 of the 6-high performing, and just 2 of the 23 low performing athletes reported an accumulated volume of constraints-based practice of more than 70.5 hours, approximately equating to 1 hour and 45 minutes per week. These findings would support the notion from chapter 2 that higher proportions and volumes of constraints-based coaching would seem be encouraged for the attainment of high performance in weightlifting.

3.6 Summary Model

A summary model was produced using a Bayesian pattern recognition analysis to determine the final model of features which was to be put forward to classification. To create the model, feature selection was performed on all normalised attributes (such that the minimum and maximum values for each attribute was represented as 0 and 1, respectively) in the data.

Table 13. The list of attributes selected for the summary model, along with their rating of importance and direction of influence on weightlifting performance.

Attribute	Importance level	Direction of influence	
		'High' Performance	'Low' Performance
Demographics and Family:			
1. School main place for sport participation (6 - 12 years)	Very important	+	-
Psychosocial			
2. Perfectionism: Doubts about actions	Fairly important	-	+
Sport participation history and weightlifting specific involvement:			
3. Flexibility/mobility training at age 11	Important	+	-
4. Flexibility/mobility training by age 14	Very important	+	-
Practice Activities			
5. Proportion of information received as demonstration at T1	Important	+	-
6. Proportion of extrinsic feedback by T1	Important	-	+
7. Volume of flexibility/mobility practice by T1	Important	+	-
8. Volume of snatch whole practice by T1	Fairly important	+	-
9. Change in proportion of information received as video feedback information between T1 and T2	Fairly important	+	-

This process determined a model of 11 features which were grouped into three distinct levels of importance based on their appearance in the top 20 features of all four, any three, or any two of the FS algorithms, respectively. Table 13 shows the features in this final model. For next step in the analysis, the model's ability to differentiate the performance groups was assessed against four different classification algorithms. For this step, four commonly used classification algorithms were used, namely the Naïve Bayes (cf. John & Langley, 1995), J48 decision tree (cf. Quinlan, 1993), Support Vector Machine (SMO; cf. Platt, 1999) and K-nearest neighbours (Aha et al., 1991). This classification process was performed iteratively using a leave one out cross-validation procedure in order to minimise overfitting the findings to the data and thus preserving the generalisability of the resulting model. The result of this classification process can be seen in table 14. As table 14 shows, the model was able to differentiate 91% of the sample across all four classification algorithms successfully. An average area under the curve (AUC) of 0.87 also indicates that this model contains a moderate to high predictive power (Obuchowski et al., 2004). The final model with normalised group means is shown as a radar plot in figure 9. As is shown, clear separation exists between the groups on each attribute in the model.

Table 14. Summary statistics for all four classification algorithms.

Classifier	Accuracy	Sensitivity	Specificity	Area under ROC curve
Naïve Bayes	96.55%	1.000	0.833	0.986
Support Vector Machine	96.55%	1.000	0.833	0.916
J48 Decision Tree	82.8%	0.913	0.500	0.836
K-Nearest Neighbour	86.2%	0.957	0.500	0.728
All Classifiers	90.5%	0.967	0.667	0.867

Accuracy = Correctly classified observations / total number of observations. Sensitivity = 1 – false positive rate. Specificity = 1 – false negative rate. Area under ROC curve is a measure of model's ability to correctly distinguish the two groups. ROC = Receiver operating characteristic.

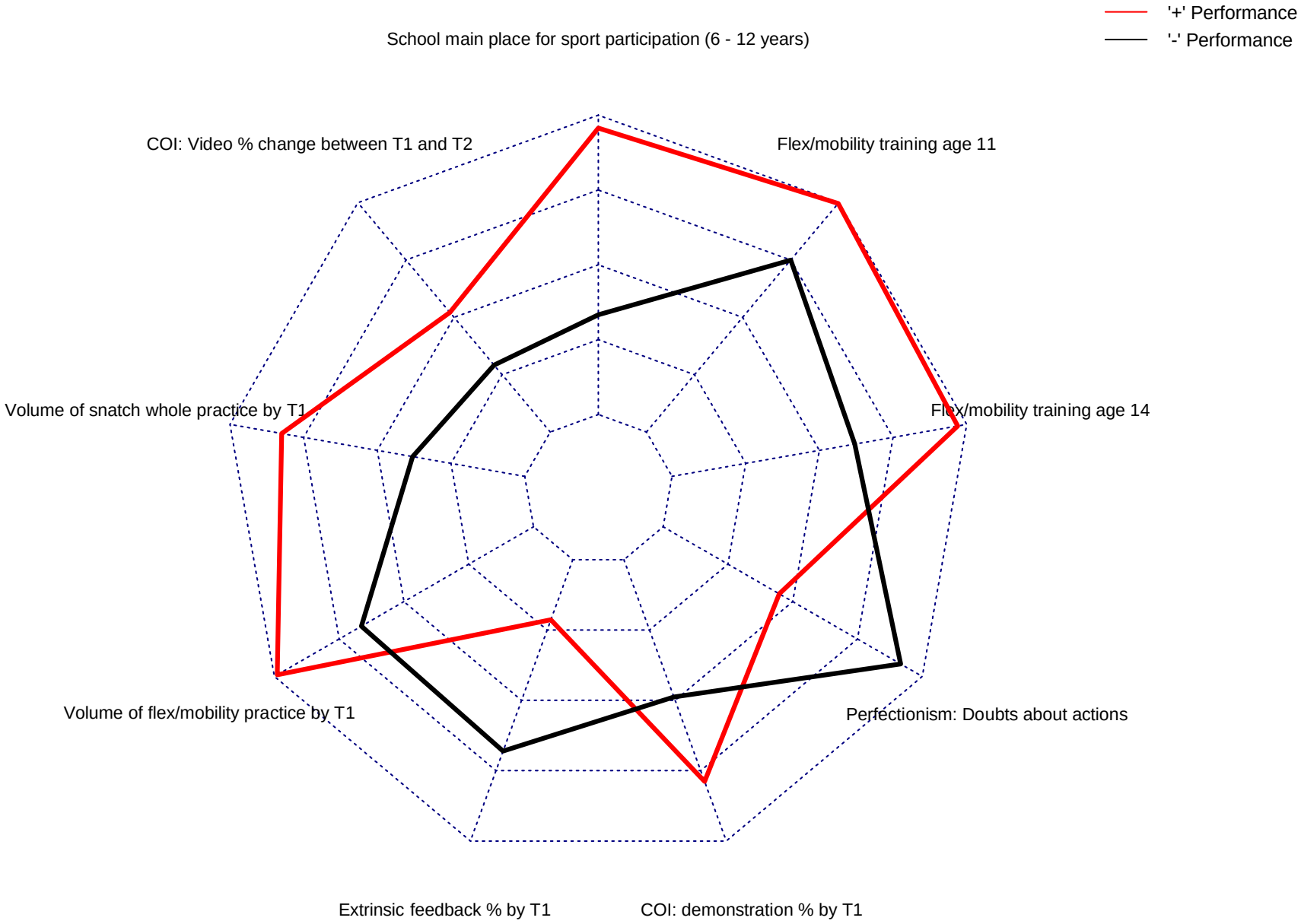

Figure 9. A radar plot depicting the normalized means for both performance groups on each attribute in the summary model. Note: Attributes are placed clockwise by order of chronological occurence starting from participation in sport at school.

4. Discussion

The findings from the current study shows that the development of elite performance is indeed a complex multidimensional construct. Differences between the performance groups were observed within each domain of expertise development and characterizes the development of high performance in weightlifting as a construct which emerges from a specific set of antecedents, which is then fostered by early exposure to environments that encourage the emergence of desired motivational and physiological traits, and is then honed with extensive exposure to conditions of practice that promote robust performance in competition. The findings from the current study will be discussed within the framework outlined in the introduction of this chapter:

4.1 Demographics and family sport participation

In line with the findings from that of chapter 3, the current findings would suggest that general weightlifting participation in Wales tends to occur in higher densely populated (i.e., less rural) communities. As discussed by Rossing et al. (2016), towns with higher population densities tend to attract talent development strategies which incorporate development clubs for more urban areas. As most sports clubs in Wales are part of a services open to the general public, such as in schools, health and fitness or Cross fit clubs. Towns with higher population densities will often have the infrastructure which will incentivise local authorities or business to offer these services to public. This finding therefore supports the findings found with the senior athletes in chapter 2 of the thesis, and therefore re-affirms the suggestion that the population of the longest residing homeplace is an important feature in the development of high performance in junior weightlifting athletes, which is in accordance with the original premise of the birthplace effect (Côté et al., 2006).

The findings from the demographic profiling of the athletes also suggest that sport participation whilst at school during the sampling years was an important feature in the

development of high performance in weightlifting. Given that most of the athletes in the study had started weightlifting training from 12 years old or older, it therefore suggests that, in line with the affordances for sports participation discussed previously, the provision of sport participation during these years encouraged the sampling of sporting activities which could have fostered the motivational and physiological characteristics necessary for high performance in weightlifting. Taken together with the findings for town size, perhaps schools in more highly populated towns in Wales offered more provision of sports facilities and access to coaching in schools than schools in more rural communities.

The current findings also highlight a clear parental influence, particularly from a father figure, on engagement in weightlifting to begin with, which is in line with the findings from that of chapter 3, as well as previous finding that have reported parental influences on child sport participation (Fredricks & Eccles, 2005; Stevenson, 1990; Xiao Lin Yang et al., 1996).

4.2 Physiological characteristics

4.2.1 Anthropometrics

These findings also highlight the importance of longer body segment lengths as a facilitator of weightlifting performance in this sample, particularly in the lower extremities of the body (i.e., the tibia). A potential explanation for this finding could be due to the mechanical advantage that longer limb lengths place on the biological lever systems of the body. This is also in accordance with the findings reported by Musser and colleagues (2014), who observed that thigh length in female weightlifting athletes in the 53kg class produced less horizontal displacement of the barbell (when observing its trajectory from the side) in the second pull of the snatch (Musser, Garhammer, Rozenek, Crussemeyer, & Vargas, 2014). In addition, the longer tibia length could also aid to facilitate a much more upright position in the overhead squat, which would imply a much more even weight distribution in the receive and recovery positions of the snatch lift.

4.2.2 Stretch shortening cycle utilization and maximum dynamic strength

As is to be expected, clear differences in the explosive power and maximum dynamic strength profiles of the athletes were found. These findings highlight the direct relevance of stretch cycling utilization and lower body power production for weightlifting performance and are also in line with the findings of Fry et al. (2006) who have reported CMJ height to be a discriminator of weightlifting performance in American junior weightlifting athletes. The findings also reaffirm the efficacy of deploying tests of lower body power, such as the CMJ and the SJ, to run alongside the athletes regular training programmes.

4.3.3 Trunk Stability

Noteworthy findings were also reported in the position of the trunk during the overhead squat, which could serve as a proxy indicator of the finish position of the snatch lift. As previously mentioned, the findings suggest that the ability to achieve a position in the squat which allows the angle of the torso to be open enough to support the position of the barbell will support a balanced weight distribution throughout the squat. This could also perhaps be linked to the longer tibia lengths also reported in the high-performance group. The findings are also in support of the findings reported by Fry et al. (2006) in which larger angles of the torso were reported in the elite junior sample. Moreover, the findings also highlight the importance of regular assessment of the torso position during the squat lift in the development of weightlifting athletes.

4.3 Psychosocial profile

4.3.1 Athlete personality

Both common and discriminatory features were observed in the athlete's personality. For the common features, both agreeableness and emotional stability were found to be common amongst the weightlifting sample, which highlight the importance of these characteristics as prerequisites for engagement in weightlifting. For agreeableness, this trait could have emerged

as a result of being physically active in sport, particularly in weightlifting, as recent longitudinal evidence has highlighted that physical activity served to preserve agreeableness in a group of adults (Stephan, Sutin, & Terracciano, 2014). In relation to emotional stability, the very nature of weightlifting as a sport itself could have naturally selected individuals with this personality trait, as the ability to maintain emotional stability under pressure is also a necessary determinant of successful weightlifting performance.

The factors in the athlete's personality that were discriminative of performance were three of the big five personality characteristics: conscientiousness, extraversion, openness to experience, in addition to some features of perfectionism, such as organization and doubts about actions. The findings for conscientiousness appear to be in accordance with the positive association between conscientiousness and characteristics associated with performance in the literature (Hardy et al., 2017; Woodman et al., 2010). For instance, conscientiousness was positively associated with quality of preparation for a competition in British gymnastic athletes (Woodman et al., 2010). Conscientiousness also appeared to be commonality amongst both elite and super elite British athletes (Hardy et al., 2017) which further emphasizes its necessity as a determinant of elite performance, particularly amongst British athletes. Conscientiousness has also been linked with other psychological constructs that have been reported as discriminators in the current study. It was reported to have to strongest association with harmonious passion of the big five personality traits ($r = 0.30$; Balon, Lecoq, & Rimé, 2013), an association which was attributed to competence, search for success (Bouvard, 2002), and engagement with specific tasks and goals (John & Srivastava, 1999).

Extraversion refers to the tendency to attain feelings of positive affect or gratitude from outside of oneself (Wiggins, 1968). In a recent study conducted via an online survey, extraversion was found to be positively associated with harmonious passion ($r = 0.18$; Balon et al., 2013). It was postulated that positive association would be attributed to the tendency of

both extraversion and harmonious passion to result in feelings of positive emotion. Of particular note was that the majority of the sample used in that study were from participants whose main activity was an individual sport. Given that harmonious passion also appeared as a discriminatory feature in this sample (see section *3.3.2.2.6*), it is likely that this positive association could also be apparent in this study.

Openness describes the breadth, depth and complexity of an individual's mental and experiential life (Costa, McCrae, & Dye, 1991). In addition to extraversion, openness has also been shown to be positively associated with harmonious passion (r = 0.20; Balon et al., 2013), which has been attributed to a tendency for curiosity, imagination, and aesthetic sensitivity in the openness to experience construct (Bouvard, 2002). Openness to experience has also been shown to positively associate with scores for sensation seeking (e.g. Tok, 2011). Sensation seeking would be described as the tendency to seek out varied, novel, and intense sensations and experiences, which is often accompanied by heightened risk taking (Zuckerman, 2015). Perhaps given the intense nature of weightlifting, particularly during competition, athletes could be more attracted to engage in training for the purposes of sensation seeking in competition.

The finding for organization confirms the importance of athletes to be meticulous in their preparation for competition, particularly with regards to their pre-planned routines, in order to attain high levels of performance. This finding also supports previous findings that have demonstrated that adaptive forms of perfectionism, such as organization, can lead to subsequent benefits on performance (e.g., Hamachek, 1978; Lundh, 2004; Silverman, 1999). Moreover, when combined with high personal standards to formulate an adaptive perfectionism construct, organization was shown to be a positive predictor of both controllable and uncontrollable sources of self-confidence, with stronger positive relationships found for the former (Machida, Marie Ward, & Vealey, 2012). It is conceivable that the high levels of

organization reported in the high-performance group in this study could have promoted higher forms of self-confidence both in relation to approaching training and competition.

As a maladaptive form of perfectionism that was prevalent in the non-elite sample, doubts about actions represents the degree to which individuals feel uncertain about or dissatisfied with the extent with which personal tasks are completed (Frost, Marten, Lahart, & Rosenblate, 1990). Given that doubts about actions represents a maladaptive form of perfectionism, this finding would also be in accordance with the notion that maladaptive forms of perfectionism would be detrimental to the development of high performance. For instance, Hall, Kerr, & Matthews (1998) reported that doubts about actions significantly predicted both cognitive and somatic state anxiety in high school runners prior to an event. Additionally, Machida et al. (2012) found that doubts about actions, along with concern over mistakes, was positively associated with attitudes towards the attainment of self-confidence from uncontrollable sources (i.e. that which is based on situational outcomes). Taken together, these findings lend support to the notion that doubts about actions, as well as other forms of maladaptive perfectionism, could ultimately hinder the preparedness of the athlete, particularly prior to competition, both in terms of levels of anxiety and in terms of controlling one's sources of self-confidence. It is therefore likely that the high doubts about actions displayed in this study could have served to have a detrimental impact on the performance of the low performing group.

4.3.2 Attitudes towards training and competition

Like athlete personality, both commonalities and discriminators features in the athlete's attitudes to training and competition in weightlifting. More specifically, the commonalities, and thus the features of participation in weightlifting, were found to be performance avoidance and concern over mistakes, whilst the discriminative features were found to be both forms of mastery-oriented achievement motivation (i.e., both approach and avoidance), performance

approach achievement motivation, harmonious and obsessive passion, commitment to training, a high relative importance of sport in relation to other life commitments.

The common features, although part of two different theoretical constructs (i.e., achievement motivation and perfectionism) are rather similar in context. Performance avoidance refers to the motivation to avoid performing poorly relative to their peers, whilst concern over mistakes refers to the degree with which one is concerned about performing poorly. Nonetheless, the findings would appear to suggest that participation in weightlifting would involve some form of motivation to avoid poor performances both in training and competition.

For the discriminatory features, finding for mastery approach highlights a somewhat significant distinction with regard to the motivational drivers for the high-performance group. Mastery approach describes the striving for the attainment of competence at a task that is based on a self-referenced standard (Roberts et al., 2012). This self-referenced standard would facilitate the engagement in a task for the purposes of surpassing of one's own previous performances, or towards the attainment of an absolute standard of competence (i.e. an objective ideal standard as opposed to a relative or socially prescribed standard of competence). Individuals high in this trait are suggested to demonstrate adaptive achievement behaviours, which leads to a myriad of positive outcomes such as increased intrinsic motivation (Elliot & Harackiewicz, 1996), positive evaluations of competence (Cury et al., 2003), and absorption in the task (Cury et al., 2002). Perhaps most pertinent to the sport of weightlifting, however, is the effect of reduced state anxiety (Cury et al., 2003), as this may have particularly important implications for the emotional states that athletes may experience in competition as a result of the adoption of mastery approach.

Many antecedents of mastery approach have been identified in the literature (see Roberts et al., 2012, for a review). Of particular interest to the current study is the antecedents

that could have been fostered within the development of the athlete's personality (Elliot & Thrash, 2002). Elliot and Thrash (2002) defined the concept of approach temperament as being a personality-based antecedent of approach motivation. They found that this construct was composed of three predominant factors. The first was extraversion which the authors referred to as the degree of sociability and optimism and was positively associated with approach temperament. Interestingly, there was also a positive association with extraversion and mastery approach. The second construct, which was termed positive emotionality and was conceptualised as a tendency to experience positive emotion and thus engage life in a positive manner (Tellengen, 1985; Watson & Clark, 1993), was also positively associated with approach temperament. The last factor was from Gray's (1970) conceptualization of the behavioural activation system (BAS). This system is a conceptualization of our central nervous system which is suggested to facilitate behaviour and produce positive affect. The integration of these three subcomponents was shown to promote a predisposition to engage in approach motivation. Given that extraversion also appeared as a discriminating feature in this study (see section 3.3.2.2.2), it is likely that the high-performance athletes in this sample were predisposed with an approach temperament. This interpretation would not be without its reservations, however, as positive emotionality and BAS were not explicitly measured in this study.

Mastery avoidance, on the other hand, describes a maladaptive form of achievement motivation, as it has been linked with broadly undesirable achievement processes such as disorganisation, emotionality, surface processing and state test anxiety (Elliot & McGregor, 2001). Like mastery approach, this construct appears to have important potential implications for emotional responses under pressured conditions due to its positive association with state anxiety. Mastery avoidance has also been linked with a variety of antecedents which could potentially have important implications for the findings in the current study. For instance, mastery avoidance has been positively associated with competence valuation, fear of failure,

parental person-focused negative feedback and parental worry (Elliot & McGregor, 2001). The concept of fear of failure has also been additionally reported by Conroy and colleagues (Conroy, 2004; Conroy & Elliot, 2004; Conroy, Elliot, & Hofer, 2003). Whilst not included as part of this study, it is certainly worth considering that a degree of fear of failure could have been an underpinning influence for the high levels of mastery avoidance reported in the low performing group in this study.

This finding that performance approach is associated with high performance in weightlifting is somewhat unsurprising for two predominant reasons. The first is in relation to the context of weightlifting (and sport more generally). Given that of the fundamental premises of competition is to outperform others, one would expect high performing athletes to be motivated to train and compete for the purpose of outperforming their peers to some degree, and as such one would expect them to score highly on this construct. This notion would also be accordance with the higher volumes of deliberate practice reported in the high performing group (see section 4). The second is in relation to the previous findings which have shown that performance approach has been associated with higher levels of performance in athletes (e.g. Elliot & McGregor, 2001).

Perhaps what is less intuitive to interpret is the degree with which the low performing athletes tended to report lower levels of the performance approach construct. On the basis of the aforementioned premise of weightlifting, it would have been somewhat reasonable to expect that all athletes in the current study would have been motivated to outperform others to some degree, and as a result the performance approach construct could have been hypothesised to be a commonality rather than a discriminator. However, as performance approach did not appear as prevalently in the low performing group, as well as that of the high performing group, it is likely that this group were adopting performance avoidance as their predominant form of achievement motivation. This type of motivation has been proposed to occur when one

typically perceives effort and ability as separate constructs (i.e. consequently leading to be ego-involved), which often leads to maladaptive achievement behaviours when the perception of ability is low (Nicholls, 1984).

The fact that both performance approach goals appeared as discriminating features in this sample highlights the importance for both task- and ego-oriented forms of achievement motivation to occur in tandem for the attainment of high performance. Thus, it would appear that the encouragement of task mastery alone would not be sufficient in the attainment for high performance, and that a motivation that is focused on outperforming others would also be necessary (Hardy, 1997). This observation is also supported in the recent GBM study, in which it was reported that super elite athletes had both a mastery and outcome focus relative to their elite counterparts (Hardy et al., 2017).

This finding that both forms of passion for weightlifting was discriminative of performance would appear to be in line with previous research that as investigated the influence of passion on the attainment of higher performance (Vallerand et al., 2007; Experiment 1), in which this positive association was also mediated by engagement in deliberate practice. It is therefore likely that the higher passion displayed by the high performing athletes in this sample served to facilitate increased engagement in deliberate practice, which ultimately led to higher levels of performance.

This also directly links with the finding that the athletes reported higher levels of commitment to training and relative importance of sport. Taken together with the results for the achievement motivation constructs reported above, as well as that of the higher volumes of weightlifting specific practice reported in the high-performance group, this result clearly suggests the higher performing group in this study were more committed to the development of their own performance through practice. This finding of commitment to training would conform to the notion of deliberate practice as a fundamental prerequisite to the attainment of

expertise (Ericsson et al., 1993). These findings also provides further support for the findings provided by Hardy et al. (2017), which have identified a that commitment to training and a high relative importance of sport was a discriminating feature in the attitudes of super elite athletes when compared with their lower achieving counterparts.

4.4 Sporting history and weightlifting specific involvement

Very similar to the findings reported in chapter 3, common and discriminative features were found in the sporting history of the athletes. Most athletes, irrespective of performance, were involved in some form of sport from in their early development, whilst involvement in strength and conditioning and flexibility and mobility training tended to be most common in higher performing athletes throughout their middle years of development. In relation to sport participation more generally, these finding therefore reaffirm that early sport participation is a necessary feature of weightlifting participation, which encourages athletes to be exposed to the motivational characteristics associated with sport participation (Côté et al., 2003a). This is particularly true for a sport such as weightlifting, in which the ratio of training to competition time is high relative to other Olympic sports, and as such the motivation to sustain a training for extensive periods must be an important feature. This also suggests that the engagement in high volumes of weightlifting specific practice from a very early age is not a prerequisite for the attainment of high performance in weightlifting. In combination with the findings for the sampling of sport, these findings further support the need for sampling outside of weightlifting to occur at an earlier age, perhaps to facilitate the development of enjoyment of sport participation and to also foster motivational characteristics for sports participation.

Whilst early involvement in weightlifting specific practice did not appear to be necessary for the attainment of high performance, the findings do however suggest that investment in weightlifting should occur much sooner in high performing athletes, typically from the end of the middle years of development (i.e., from the age of 15 years of ages). This

would generally be in accordance with the findings reported in chapter 3, as higher volumes of time devoted to deliberate practice in weightlifting was reported from the 15 years of age milestone.

4.5 Microstructure of practice

With regards to the microstructure of practice, many of the findings reported in the current study conformed to the narrative of the findings reported in chapter 3. More specifically, the current findings demonstrated that (1) athletes committed to a higher volume of mental skills development and were exposed to more vicarious experiences; (2) information was predominantly conveyed to high performing athletes verbally, yet the use of video information appeared to be particularly prevalent; (3) the majority of the high performing athletes practice involved practicing the lifts as whole movement; (4) practice conditions, although predominantly constant, were more varied in high performing athletes; (5) significant proportions of practice conditions in the high performing athletes were both anxiety and context specific; (6) higher volumes of practice with both external and internal attentional foci were observed in higher performers; (7) proportionately more intrinsic feedback was reported in higher performing athletes; and (8) higher proportions and volumes of constraints based coaching were reported in higher performing athletes.

As the findings are in accordance with the findings reported in chapter 3, the discussion points, as well as the supporting literature, can be found in the discussion of section 3. There are however two additional points that were worthy of mention in relation to (1) sources of feedback the athletes used, and (2) focus of attention.

As the proportions of intrinsic feedback were higher in the high-performance group, it would also be worth considering the quality of the feedback that is likely to be produced between the groups. When taking into account that the high performing group reported higher ratings for mastery and performance approach (see sections 3.3.2.1.1 [mastery approach] and

3.3.2.1.3 [performance approach]), and most of the low performing group reported higher levels of mastery avoidance (see section *3.3.2.1.2*), this opens the potential for differences in the type of intrinsic feedback produced between the groups. For instance, could the high performing group be reinforcing more task mastery-oriented forms of feedback whilst the low performing group be generating feedback that is based on the avoidance of incompetence? Future research should aim to test this proposition, as this could have potentially importance consequences for the reinforcement of training behaviours.

Whilst no differences were reported in the proportions of practice with different attentional foci, this finding does support the notion of the accumulations of high practice volumes whilst adopting a combination of an internal and external focus of attention. When probed about the types of attention adopted, most of the athletes reported alternating their attention between internal and external focuses. For instance, some athletes would focus their attention on the movement of their elbows (internal) whilst also ensuring that they maintained a good proximity to the trajectory of the bar (external). Some athletes also mentioning adopting proportionately more internal focus for movements in which they wanted to appreciate the 'feel' of, whilst others mentioned just wanting to drive the bar upwards as fast as possible, which would require predominantly external focus. The findings does not provide particularly strong support for the original tenets of the constrained action hypotheses (Wulf, McNevin, & Shea, 2001; see Wulf, 2007, for a review), which mainly asserts that the adoption of an external focus of attention for the benefit of performance accuracy, both in terms of movement outcome (e.g., McNevin & Wulf, 2002; Wulf et al., 2001), and movement kinematics (e.g. Lawrence, Gottwald, Khan, & Kramer, 2012; Lohse, Sherwood, & Healy, 2010).

4.6 Concluding remarks

The findings from the current study do indeed demonstrate that the development of elite performance is indeed a complex multidimensional construct, and characterizes the

development of high performance in weightlifting as a construct which emerges from a specific set of antecedents, which is then fostered by early exposure to environments that encourage the emergence of desired motivational and physiological traits, and is then honed with extensive exposure to conditions of practice that promote robust performance in competition.

More specifically, these antecedents take the form of living in a homeplace throughout one's development which has the appropriate infrastructure and opportunities for early sport participation, particularly for schools that offer the provision of sport participation from as early as 6 years of age. This early sport participation should include activities which promote flexibility and mobility training, as well as general functional conditioning activities, from as early as 9 years of age. Then, likely as a result of having parents whole also participate in sport, these individuals are encouraged to participate in weightlifting from around the age of 13 to 14 and are likely to begin investing into their weightlifting development, perhaps as a result of containing the appropriate anthropometric profile and demonstrating considerable strength and power adaptions, from around 15 years of age. Additionally, perhaps as a reflection of their conscientious, open-minded, and extravertive personalities, they develop a strong passion for weightlifting which places their relative importance of the sport very highly in comparison with other commitments. This manifests itself as a strong commitment to training, an approach to training that is focused on the attainment of both an absolute (i.e., an objective) and relative (i.e., a peer-related) standard of competence, as well as a high degree of organization in preparation for a competition that increases their sense of self-confidence, and perhaps reduces any sense of doubt about their own actions. These behaviours may also be gathered implicitly from learning vicariously through more experienced weightlifting athletes, as well as through means of mental reinforcement outside of the training environment. In training, they engage in extensive volumes of weightlifting specific practice in a setting that offers a constant and predictable environment, as well as in training settings that offers variation to the athlete, such

as in a different club. They practice the execution of the snatch and clean and jerk both as whole movements, as well as in assistance exercises which enable practice of each movement to be broken down into parts. They are sure, however, to sustain an optimal proportion of the technical practice for both lifts as they are intended for competition (as whole movements). Throughout their training, they initially receive a high proportion of information from their coach through verbal instruction and physical demonstrations but are encouraged to progressively use more video information sources the more experienced they become. Feedback about their performance is mainly through extrinsic means, although they tend to produce higher proportions of feedback from their own sensory sources with experience. This feedback is likely guided by their mastery- and performance- approach motivation. Finally, in the lead up to a competition, their training begins to closely meet the demands of competition, both in relation to context and the perception of anxious states, which allows them to optimally transfer onto the competitive stage.

The findings from the current study also extend the findings from the study in chapter 3 by examining the holistic profile of talent development longitudinally, which further reaffirm the notion that the development of high performance in weightlifting stems from a specific combination of features of the framework discussed in chapter 1. Moreover, whilst this combination may support generalized theoretical concepts, such as early sport sampling and extensive deliberate practice, the novelty in these findings lie in the notion that the holistic profile reported thus far is indeed specific to the sport of Olympic weightlifting.

Chapter 5

To thrive or survive? Relative age effects in weightlifting.

Abstract

In a three-part investigation, Chapter 5 comprehensively examined the prevalence of the relative age effect at the highest level of representation in weightlifting. Experiment 1 examined the historic performance data from all youth, junior, and senior Olympic, world, commonwealth and continental championships in order to determine the prevalence of the relative age effect in medallists compared with non-medallists in the light-, middle-, and heavyweight bodyweight categories. Multiple logistic regressions revealed a reduced prevalence of the RAE in medallists at heavier weight categories as athletes progress through the pathway, with some gender related nuances being observed. Experiment 2 examined the longitudinal retention from youth to senior age groups by birth quarter. A higher proportion of Q4 athletes transitioned from being a non-medallist to a medallist compared to Q1 athletes as they progress through the pathway, with some nuances for weight category type being observed. Experiment 3 explored the psychosocial characteristics that account for the relative age. Machine learning was used to produce a predictive model that classified a sample of junior weightlifting athletes based on birth quarter with 80% accuracy. This predictive model identified mastery approach, concern over mistakes, emotional stability, and openness to experience as important psychosocial constructs.

KEYWORDS: Relative age effect; Olympic weightlifting; elite performance; elite athletes; talent development

1. Introduction

Sociologist Robert Merton (1968) first popularised the concept of 'unintended consequences' when deliberating the often-unforeseen effects of purposeful social action. These tend to occur when humans attempt to exert control on what is arguably a complex and chaotic universe. The very act of developing athlete cohorts based on predefined age-brackets, in an attempt to apply parity to an environment, can in some instances achieve the very opposite (Wattie, Schorer, & Baker, 2014a). This particular paradigm was first observed by Barnsley, Thompson, and Barnsley (1985) who remarked on an extraordinary linear relationship between 'birth-month' and the 'proportion of players selected within a national hockey programme'. The term 'relative age effect' (RAE) was adopted to account for this phenomenon and highlight the significant developmental advantages and thus, selection bias, for those born earlier in the year within an athlete cohort. Whilst broader findings have observed similar findings across a number of sports (for a meta-analysis see Cobley, Mckenna, et al., 2009), there is sufficient evidence to suggest both inter- and intra-sport differences based on a number of multidisciplinary mechanisms at play. As things stand, the complexity of these bio-psycho-social mechanisms, and subsequent influence on RAE, has likely been underestimated in current literature.

The most palpable mechanisms underpinning RAE are arguably biological in nature, with physical advantages of early maturation including enhanced speed, strength and coordination as just a few examples likely to influence athlete selection (Barnsley et al., 1985). Wattie, Schorer and Baker (2014) propose an increased prominence of RAE in sports that are biased towards such physical attributes, such as rugby or basketball. Similarly, gender has been identified as an important determinant of RAE, whereby the aforementioned physical advantages of early maturation are often more pronounced in the male population (Okazaki, Keller, Fontana, & Gallagher, 2011; Schorer, Cobley, Büsch, Bräutigam, & Baker, 2009).

More recently, a sociological model assimilating a number of pre-existing theories has been used to account for the role of social agents (e.g. coaches and parents) in influencing RAE (Hancock, Adler, & Côté, 2013). Hancock et al. suggest that Matthew effects, whereby 'the rich get richer and the poor get poorer' (Merton, 1968), are perpetuated in sport by social mediators, e.g. parents enrolling chronologically older children into sports earlier and thus, inadvertently facilitating more opportunities for them. Similarly, Hancock and colleagues use Pygmalion effects (Rosenthal & Jacobson, 1968) to describe a type of self-fulfilling prophecy whereby greater expectations from significant others leads to greater results e.g. a coach facilitating increased game time or individualised coaching based on enhanced expectations of an athlete. These social agents may also include policy makers. One such example of this is the presence of weight categories within a sport e.g., weightlifting or combat sports. Researchers have hypothesized an elimination of RAE in sports where weight categories are in existence (Delorme, 2014). However, the only study to yet consider the presence of weight categories in the context of RAE, revealed mixed findings, and neglected to investigate between-weight category effects (Delorme, 2014). It is possible that any intra-sport differences as a function of weight category, may have acted as an extraneous variable, confounding overall findings. This methodological shortcoming clearly warrants further scrutiny. Furthermore, the somewhat paradoxical hypotheses surrounding sports biased towards physicality, where we would expect an increased prevalence of RAE, combined with the notion that the presence of weight categories within a sport's structure may in fact eliminate RAE (Delorme, 2014), makes the sport of weightlifting worthy of investigation.

Finally, psychological mechanisms have also been identified as an important contributing factor to RAE. Where Pygmalion effects refer to the influence on the behaviour of social agents once expectations about an athlete have been set, Galatea effects (Merton, 1957) refer to the expectations and behaviours of the athlete themselves in a self-fulfilling prophecy e.g. raised confidence or work ethic. Psychological hypotheses to account for RAE findings have also emerged

when investigating the super-elite end of the performance spectrum (Gibbs, Jarvis, & Dufur, 2012; Jones et al., 2018; McCarthy, Collins, & Court, 2016), where reversal or inverse effects emerge. Gibbs et al. (2011) term this ‘the rise of the underdog’ whereby relatively younger players benefit psychologically from longstanding exposure to higher levels of challenge. This notion is supported by a host of literature underlying the paradoxical benefits of adversity or a ‘rocky road’ (Collins & MacNamara, 2012; Hardy et al., 2017; Rees et al., 2016). However, it is important to note that psychological underpinnings of RAE remain hypothetical in nature.

Wattie et al. (2014) argue that RAE is likely a more complex interaction between individuals and their environment. They propose a developmental systems model, based on Newell's (1986) constraints approach to motor learning, whereby individual constraints (such as birth date and gender), interact with task constraints (such as sport type, expertise level and positional role) and environmental constraints (such as sport policy, structure and continent) to influence the ensuing RAE. However, this model is yet to be tested and despite these often complex and multidisciplinary processes, RAE is typically investigated using cross-sectional approaches and neglects to consider the likely dynamic nature of this phenomenon over time. As such, Faber et al. (2019) emphasise the likelihood of RAE reducing as a function of chronological age, but this is yet to be tested within a longitudinal model.

In addition to the oversimplification of a complex phenomenon and adoption of inappropriate cross-sectional designs used to understand a concept that is arguably dynamic in nature, a further shortcoming of RAE literature is the assumptions of success based on selection to or presence on a team alone. The only paper to the authors’ knowledge to attempt to address limitation is Jones et al. (2018) who used a selection of 11 criteria developed in collaboration with national coaches to identify super-elite level cricketers when investigating RAE. However, these criteria are arguably subjective in nature and may therefore lead to inaccuracies.

Over the course of three experiments, we addressed the aforementioned limitations and provided the first test of Wattie et al.'s (2014) developmental systems model. As such, we investigated RAE in the context of individual. task and environmental constraints; whereby individual constraints included an athlete's birthdate, gender, performance success and psychological make-up; environmental constraints included the bodyweight classifications imposed on the sport through policy makers; and task constraints included the sport-specific nature of analysis in weightlifting and the developmental stages of the pathway. This longitudinal approach allowed us to better investigate the dynamic nature of RAE and scrutinise athlete retention as a function of birth quarter from youth to senior.

1.1 Experiment 1

The rationale behind experiment 1 was threefold: firstly, the authors wanted to investigate some of the aforementioned individual constraints of RAE including gender and bodyweight classification. The current authors hypothesised possible intra-sport differences in weightlifting whereby a stronger RAE may exist in higher weight categories. This is in line with literature demonstrating stronger RAEs in sports that are biased towards physicality (Wattie et al., 2014). Furthermore, based on the increased prominence of physical developments following biological maturation in males, we expected to see a more pronounced RAE in male athletes (see also Schorer et al., 2009). Secondly, we wanted to investigate RAE longitudinally over the course of a talent pathway and thirdly, we wanted to investigate the RAE more closely in line with athletic performance by using medal attainment as a more objective measure of success.

1.2 Methods

1.2.1 Participants

Research was conducted in line with institutional ethical guidelines and data collected from the publicly available competition results archive on the International Weightlifting Federation's (IWF) webpage (www.iwf.com). This included a total of 45,988 athlete results from all

international youth, junior and senior events held between 1998 and 2018. Youth events included results from athletes ranging from 13 to 17 years of age, whilst junior events included results ranging from 15 to 20 years, and Senior events athletes who ranged from 15 years or above. Given the considerable overlap between age groups, athletes were limited to a single entry in the dataset by selecting the entry in which they were ranked the highest. As such, the dataset was filtered to a sample of 12,855 athletes. This included results from a total of 280 competitions. All were IWF commissioned, meaning that athletes were only eligible to compete through meeting qualification criteria recognised by either the IWF, the Commonwealth or Olympic committees, or respective continental federations. Competitions were tiered such that the highest possible level was the Olympic Games, followed by World Championships, Commonwealth Games, and respective continental championships (i.e., African, American, Asian, European, and Oceania championships). Table 15 shows a breakdown of specific bodyweight categories by age group and gender.

For the purpose of the current study, bodyweight categories were grouped into one of three category types for their respective gender and age group: lightweight (for the lightest two categories), middleweight (for the middle three categories), and heavyweight (for the heaviest two or three categories depending on whether there were seven or eight categories in total, respectively; see table 15). This enabled us to preserve sample size in order to appropriately test for an influence of bodyweight classification on RAE.

Table 15. Breakdown of bodyweight category types

		Category Type		
Sex	Age Group	Lightweight	Middleweight	Heavyweight
Female	Youth	44kg, 48kg	53kg, 58kg, 63kg	69kg, 69kg+
	Junior & Senior	48kg, 53kg	58kg, 63kg, 69kg	75kg, 75kg+
Male	Youth	50kg, 56kg	62kg, 69kg, 77kg	85kg, 85kg+
	Junior & Senior	56kg, 62kg	69kg, 77kg, 85kg	94kg, 105kg, 105kg+

2.2 Procedure

Athlete birthdates were classified into birth quartiles in accordance with the age group cut-off dates used by the IWF. As such, athletes whose birthdates fell between January 1st and 31st March were assigned as quartile 1 (Q1), 1st April to 31st June as quartile 2 (Q2), 1st July to 31st September as quartile 3 (Q3), and 1st October to 31st December as quartile 4 (Q4). In addition to bodyweight classification, each athlete was assigned a label based on whether or not their performance had earned them a medal in their respective category. As such, athletes who placed 1st, 2nd or 3rd were assigned the label "medallist", whilst athletes who placed 4th or higher were assigned with the label "non-medallist".

1.2.3 Data Analysis

Data processing and analysis was performed using R version 3.5.2 in R Studio. All analysis was performed using functions from the base R package (Team, 2019). Chi squared goodness of fit tests (X^2) were performed on the distribution of the birth quartiles within each of the gender and bodyweight classifications as listed in table 15. Logistic regression was performed in order to determine the relative risk size of any RAE found. In line with comparisons previously used in the RAE literature (Till, Cobley, O' Hara, Cooke, & Chapman, 2010), odds ratios and 95% confidence intervals were calculated for Q1 vs Q4, Q2 vs Q4, Q3 vs Q4, as well as half year (first half [H1] vs second half [H2]) comparisons. This enabled the assessment of distributions in the context of the RAE risk to take place across all quartiles.

Finally, to further explore any potential interactive effects of bodyweight classification and medal success (medallist / non-medallist) on RAEs, separate multiple logistic regression analyses was performed for each gender using the distribution of Q1 birthdates relative to Q4 as the dependent variable, and age group (i.e., youth, junior, senior), bodyweight classification, and medal success as predictor variables. For each predictor variable, the level of the lowest order was coded as the baseline level for that variable. Specifically, the 'youth', 'lightweight' and 'non-medallist' levels were coded as the baseline level for the age-group, bodyweight classification, and medal

success predictor variables, respectively, meaning that any coefficients reported in the model are relative to the baseline parameter. For all tests used, statistical significance was determined at the 95% confidence level.

1.3 Results

Table 16 shows results for the birthdate distributions, chi-square analyses, respective odds ratios, and confidence intervals as a function of age group and bodyweight classification. Significant chi squared effects were observed across all age groups and weight categories with the exception of female junior heavyweight and lightweight categories, respectively ($X^2 = 3.87$, $p = 0.338$; $X^2 = 5.21$, $p = 0.157$). This is further supported by inspection of 95% confidence intervals for the odds ratios. Results for the logistic regression model are displayed in tables 17 and 18 for males and females, respectively and visually represented in figure 10.

Table 16. Birthdate distributions, chi-square analyses, and odds ratios with 95% confidence intervals arranged by Sex, Age Group, and Bodyweight Category

Sex	Age Group	Bodyweight Category	N	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	χ^2	P	OR (CI) Q1vQ4	OR (CI) Q2vQ4	OR (CI) Q3vQ4	OR (CI) H1vH2
Female	Youth	Lightweight	311	30.23	22.83	25.08	21.86	5.21	0.157	1.38 (0.87-2.21)	1.04 (0.64-1.7)	1.13 (0.7-1.83)	1.14 (0.82-1.58)
		Middleweight	621	31.72	26.25	23.51	18.52	22.6	<0.01	1.7 (1.22-2.37)	1.42 (1.01-1.99)	1.27 (0.9-1.79)	1.37 (1.09-1.73)
		Heavyweight	348	30.75	26.44	23.56	19.25	9.77	0.021	1.59 (1.02-2.5)	1.37 (0.87-2.17)	1.22 (0.77-1.94)	1.33 (0.98-1.82)
	Junior	Lightweight	474	36.71	20.46	21.73	21.1	34.81	<0.01	1.74 (1.2-2.52)	0.96 (0.65-1.43)	1.03 (0.7-1.53)	1.33 (1.02-1.73)
		Middleweight	755	35.5	21.19	23.58	19.74	46.64	<0.01	1.8 (1.34-2.42)	1.07 (0.79-1.47)	1.19 (0.87-1.62)	1.31 (1.07-1.62)
		Heavyweight	444	28.15	23.87	22.3	25.68	3.37	0.338	1.1 (0.75-1.61)	0.93 (0.63-1.37)	0.87 (0.59-1.29)	1.08 (0.83-1.42)
	Senior	Lightweight	500	33.2	20.6	22.8	23.4	18.8	<0.01	1.42 (0.99-2.03)	0.88 (0.6-1.29)	0.97 (0.67-1.42)	1.16 (0.9-1.5)
		Middleweight	908	30.18	24.01	22.8	23.02	13.28	<0.01	1.31 (1.01-1.71)	1.04 (0.79-1.37)	0.99 (0.75-1.3)	1.18 (0.98-1.43)
		Heavyweight	505	31.29	25.35	22.57	20.79	12.77	<0.01	1.49 (1.04-2.15)	1.22 (0.84-1.77)	1.09 (0.74-1.59)	1.3 (1.01-1.68)
Male	Youth	Lightweight	458	31.66	22.27	25.55	20.52	13.21	<0.01	1.54 (1.05-2.26)	1.08 (0.72-1.6)	1.24 (0.84-1.84)	1.17 (0.89-1.52)
		Middleweight	922	36.12	25.27	21.15	17.46	72.03	<0.01	2.07 (1.58-2.71)	1.44 (1.09-1.91)	1.21 (0.91-1.61)	1.59 (1.31-1.92)
		Heavyweight	660	36.52	25.91	22.42	15.15	62.58	<0.01	2.41 (1.73-3.35)	1.71 (1.22-2.41)	1.48 (1.05-2.09)	1.66 (1.33-2.08)
	Junior	Lightweight	639	33.96	21.28	25.2	19.56	31.62	<0.01	1.73 (1.26-2.4)	1.09 (0.77-1.53)	1.28 (0.92-1.79)	1.24 (0.99-1.55)
		Middleweight	1238	33.93	22.94	23.1	20.03	55.56	<0.01	1.69 (1.35-2.13)	1.14 (0.9-1.45)	1.15 (0.91-1.46)	1.32 (1.12-1.55)
		Heavyweight	1032	33.82	22.67	25.29	18.22	53.36	<0.01	1.86 (1.44-2.4)	1.24 (0.95-1.63)	1.39 (1.07-1.81)	1.3 (1.09-1.55)
	Senior	Lightweight	601	38.6	20.8	19.97	20.63	59.4	<0.01	1.86 (1.34-2.58)	1.01 (0.71-1.43)	0.97 (0.68-1.38)	1.46 (1.15-1.84)
		Middleweight	1307	34.28	20.28	23.95	21.5	63.65	<0.01	1.59 (1.28-1.99)	0.94 (0.75-1.19)	1.11 (0.88-1.4)	1.2 (1.03-1.41)
		Heavyweight	1131	33.95	21.31	24.14	20.6	51.51	<0.01	1.65 (1.3-2.09)	1.03 (0.8-1.33)	1.17 (0.91-1.5)	1.24 (1.05-1.46)

N = sample size, Q = birthdate quartile, OR = odds ratio, H = half year (by 6 months)

Table 17. Multiple logistic regression on Q1 vs Q4 membership for female weightlifting athletes

Term	Log odds Estimate (Standard Error)	P	Odds Ratio
Intercept	0.36 (0.24)	0.13	1.43 (0.9-2.3)
Junior	0.13 (0.29)	0.65	1.14 (0.64-2.02)
Senior	0.11 (0.3)	0.72	1.11 (0.62-1.99)
Middleweight	-0.04 (0.28)	0.88	0.96 (0.54-1.67)
Heavyweight	-0.1 (0.31)	0.76	0.91 (0.49-1.68)
Medallist	-0.07 (0.32)	0.84	0.94 (0.5-1.75)
Junior x Middleweight	0.3 (0.36)	0.41	1.35 (0.66-2.75)
Senior x Middleweight	-0.03 (0.36)	0.93	0.97 (0.48-1.95)
Junior x Heavyweight	-0.24 (0.41)	0.55	0.78 (0.35-1.75)
Senior x Heavyweight	0.1 (0.4)	0.80	1.11 (0.51-2.43)
Junior x Medallist	0.2 (0.41)	0.63	1.22 (0.55-2.71)
Senior x Medallist	-0.16 (0.4)	0.70	0.85 (0.39-1.88)
Middleweight x Medallist	0.56 (0.4)	0.16	1.75 (0.8-3.83)
Heavyweight x Medallist	0.56 (0.45)	0.22	1.74 (0.72-4.26)
Junior x Middleweight x Medallist	-1.03* (0.52)	<0.05	0.36 (0.13-0.98)
Senior x Middleweight x Medallist	-0.63 (0.5)	0.21	0.53 (0.2-1.42)
Junior x Heavyweight x Medallist	-0.8 (0.58)	0.17	0.45 (0.14-1.4)
Senior x Heavyweight x Medallist	-0.46 (0.57)	0.42	0.63 (0.2-1.92)

* *significant at the 95% confidence level*

Table 18. Multiple logistic regression on Q1 vs Q4 membership in male weightlifting athletes

Term	Log odds Estimate (Standard Error)	P	Odds Ratio
Intercept	0.67** (0.18)	<0.01	1.96 (1.38-2.81)
Junior	-0.07 (0.23)	0.77	0.93 (0.59-1.48)
Senior	-0.04 (0.23)	0.85	0.96 (0.61-1.51)
Middleweight	0.03 (0.22)	0.90	1.03 (0.67-1.57)
Heavyweight	0.16 (0.24)	0.51	1.17 (0.73-1.89)
Medallist	-0.54* (0.27)	<0.05	0.59 (0.35-0.99)
Junior x Middleweight	-0.12 (0.28)	0.67	0.89 (0.51-1.54)
Senior x Middleweight	-0.04 (0.28)	0.90	0.96 (0.56-1.67)

Junior x Heavyweight	-0.24 (0.31)	0.44	0.79 (0.43-1.45)
Senior x Heavyweight	-0.25 (0.3)	0.41	0.78 (0.43-1.41)
Junior x Medallist	0.41 (0.35)	0.24	1.51 (0.76-3.01)
Senior x Medallist	0.53 (0.35)	0.13	1.7 (0.86-3.38)
Middleweight x Medallist	0.62 (0.34)	0.07	1.85 (0.96-3.59)
Heavyweight x Medallist	0.64 (0.36)	0.08	1.89 (0.94-3.83)
Junior x Middleweight x Medallist	-0.44 (0.44)	0.32	0.64 (0.27-1.52)
Senior x Middleweight x Medallist	-1.02* (0.43)	0.02	0.36 (0.15-0.84)
Junior x Heavyweight x Medallist	-0.29 (0.46)	0.54	0.75 (0.3-1.86)
Senior x Heavyweight x Medallist	-0.72 (0.46)	0.11	0.48 (0.2-1.18)

** significant at the 95% confidence level; **significant at the 99% confidence level*

1.3.1 Females

For females, a significant developmental stage interaction x bodyweight x medal success (B = -1.03, SE = 0.52, z = -2, $p < 0.05$) was observed, which suggests opposite RAE's (measured as the log odds of Q1 membership relative to Q4 membership) were observed when comparing the middleweight and lightweight categories in the transition from youth to junior; and that this relationship was only apparent in medalling athletes (see top left plot of figure 10). No other significant main effects or interactions were observed ($p > 0.05$).

1.3.2 Males

For males, results revealed a main effect for medal success (B = -0.535, SE = 0.27, z = -1.996, $p < 0.05$), which suggests that the RAE was stronger in youth non-medallists relative to youth medallists. Additionally, a significant developmental stage x bodyweight x medal success interaction (B = -1.02, SE = 0.43, z = -2.35, $p < 0.05$) was observed. This interaction suggests that opposite RAE relationships were observed when comparing middleweights and lightweights in the transition from youth to senior; and, similar to the female analysis, this relationship was only observed in the medallists (see figure 10). No other significant interactions were observed ($p > 0.05$).

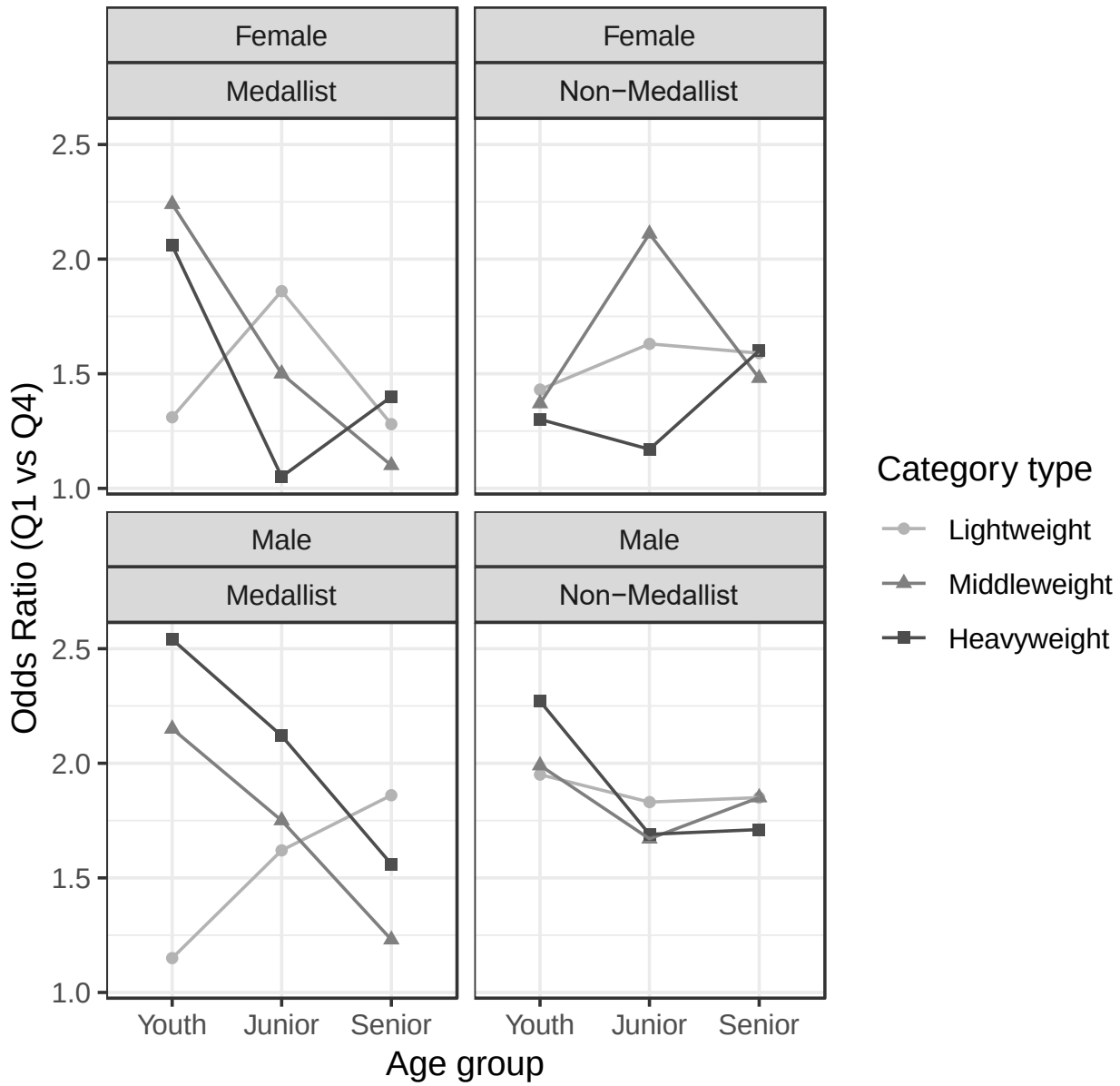

Figure 10. Odds ratios for each age group and weight category type in both male and female medallists and non-medallists.

1.3 Discussion

The rationale behind experiment 1 was to provide a more comprehensive investigation of RAE in a sport that could be broken down into its respective categories i.e., gender, bodyweight, developmental stage and subsequent performance success. These respective breakdowns were all based on theoretical rationale; e.g. gender differences grounded in the notion that biological maturation may exacerbate physical attributes more so

in males than females (Aune, Ingvaldsen, Vestheim, Bjerkeset, & Dalen, 2018), a more pronounced RAE in higher weight categories, the same way in which it is for sports biased towards enhanced physical attributes (Wattie et al., 2014), and a reduced prevalence of RAE at later developmental stages of the pathway in line with and the notion that any advantages of early maturation eventually 'level out' as athletes get closer to and eventually move beyond maturity (Faber et al., 2019).

Overall results revealed a significant RAE biased towards Q1 athletes across all developmental stages and weight categories, excluding the female junior heavyweight and lightweight categories. This suggests that the existence of weight categories within a sport's structure does not in itself diminish RAE. However, with regards to performance measures, this effect was nuanced throughout bodyweight categories, genders and development stages (see table 16).

As per previous literature, findings were consistent with the notion that RAE may reduce as a function of chronological age (e.g., Faber et al., 2019), with some gender-related nuances. For females, RAE diminished between youth (13-17yrs) and junior (15-20yrs) levels, but only for athletes in the middleweight and heavyweight categories who medalled. Male lifters also showed a reduced prevalence of the RAE between youth and senior medallists in the middleweight and heavyweight categories. Overall results seem to show a clearer trend within male compared to female findings, which is in line with hypotheses presented by Malina, Bouchard, and Bar-Or (2004), whereby physical maturational differences between males and females may influence males and subsequently RAE more so than females.

With regards to bodyweight categories, where we hypothesised a stronger RAE at higher categories, we only see this effect in youth lifters within male athletes in particular (see figure 10). Overall findings actually suggest a reduced prevalence of the RAE at higher

weight categories as athletes progress through the pathway. It is possible this is a consequence of Q1 athletes being more likely to drop out at later stages of the pathway when maturational biases are no longer in their favour and this effect is more pronounced at the higher weight categories. However, this warrants further investigation.

A similar pattern emerges with regards to medal success, i.e., RAE is more prevalent in athletes who do not medal as opposed to those who do. It is only at the youth level where we see a stronger RAE in medallists compared to non-medallists (for middleweight lifters only). Together, these findings suggest that Q1 athletes, perhaps selected based on early promise as a result of physical superiority, may not be following through in terms of their potential talent at later stages of the pathway. Lightweight lifters tended to show a slightly different pattern, with medalling male lifters more likely to show a stronger RAE as they progress through the pathway. This may, however, be a result of middleweight athletes transitioning down to a lower weight category as they get older.

Although a longitudinal design investigating different developmental stages of the pathway was used, it could still be argued that it was a cross-section of the dataset, and so the observations were limited to between-group comparisons. Thus, the findings may not extend to any effects athletes may experience as they progress throughout the system. Additionally, we were compelled to make assumptions surrounding athlete drop-out without empirical data to support these hypotheses., Experiment 2 sought to incorporate a refined longitudinal observation of athletes who had competed in youth right through to senior competitions. In short, we wanted to investigate athlete transition and subsequently retention across developmental stages of the pathway in order to better understand the RAEs observed in experiment 1.

2.1 Experiment 2

Experiment 2 investigated the retention of athletes born in different birth quarters, as they transitioned across different stages of the pathway, i.e., starting at youth before progressing through to junior and ultimately senior age groups. Typically, we would expect to see increased drop-out of Q4 athletes as they struggle to survive in a system where their physical development is inferior to their peers (see Nicolas Delorme et al., 2010). These mechanisms would normally contribute to an increased prominence of Q1 athletes within a system i.e., the RAE. However, findings of experiment 1 suggested a reduction in prevalence of the RAE in weightlifting, as athletes progressed through the pathway, especially at the higher weight categories. Therefore, we wanted to determine whether this was a result of Q1 athletes dropping out of the system at later stages of the pathway and subsequently not fulfilling their 'early promise'. We also wanted to investigate whether Q4 athletes that are able to survive early stages of the pathway, are by doing so, provided with the additional time they need to flourish into 'late bloomers'. We adopted a longitudinal approach to investigate athlete retention as a function of birth quarter, between different stages of the pathway. Data was analysed in relation to any transition between bodyweight categories and changes in medal success.

2.2 Methods

The dataset was the same for experiment 2 as it was for experiment 1, with one exception: athletes who had competed in an IWF event in the youth age group were tracked longitudinally throughout the dataset in order assess the retention of these athletes, and whether or not the retention in these athletes was in any way influenced by the RAE.

2.2.1 Participants

Athletes were retained in the dataset based on their appearance in at least one IWF competition in the youth age group. In order to ensure athletes in the dataset had time to progress from youth to senior competition levels, only youth events prior to 2014 were

included and athletes born prior to the 1st January 2000. For any athletes appearing in more than one youth competition, the entry with the highest respective rank position followed by the highest bodyweight category (in the case of a tied rank position) were used as criterion variables to filter the dataset. Consequently, a total of 3,175 athletes were included in the experimental analysis.

2.2.2 Procedure

Birth quartiles, bodyweight categories, and medal success for each athlete were determined using the same criteria outlined in experiment 1. Athletes were tracked longitudinally by filtering the names of all athletes appearing in the junior competitions in the dataset by the names of the athletes in the youth sample. Any athlete who appeared in this filtered dataset, and for whom the date of the junior competition was later than the respective youth competition, were retained for subsequent analysis. Any athlete in the youth sample that did not appear in the junior or subsequent senior sample was assumed to have dropped out from competing in IWF competitions, and thus did not form part of the retained sample. This process was then repeated for the retained junior sample by filtering this dataset against all senior competitions. This resulted in a total of 907 athletes identified as having progressed from junior through to senior competition.

For each athlete in the retained sample at both junior and senior age groups, bodyweight category and medal success were assigned to the competition entry for the new respective age group, and as such any relative change in bodyweight category and/or medallist status with age group could be determined. As per the youth sample, multiple appearances in a particular age group were reduced to a single appearance by selecting the highest ranked entry, followed by the highest bodyweight classification in the case of tied competition rank.

In order to control for any potential differential effects of maturation, such as changes in bodyweight on relative competition performance, athletes within the retained sample were grouped by their relative change in bodyweight classification and medal success, such that athletes in a given bodyweight classification who did not change bodyweight category or medal success between age groups were differentiated from those that did. This also allowed for a more detailed examination of the RAE on the transitioning pathway between age groups and bodyweight classification. As such, a total of 53 subsamples progressed through from entry (youth) to senior, each of which represented a unique combination of relative change in bodyweight classification and medal success between age groups.

2.2.3 Data Analysis

In order to assess the influence of the RAE on the longitudinal retention of youth weightlifting athletes, the distribution of retention rates across birth quartiles within each subsample were analysed using chi-squared goodness of fit tests. Retention rates for each birth quarter within each subsample was determined by dividing the total number of athletes retained within the birth quarter by the total number of youth athletes in the respective birth quarter and bodyweight category.

Based on the rationale provided by (Delorme et al., 2010) when assessing dropout in French male soccer players, goodness of fit tests were performed by comparing the observed retention rates against a theoretical distribution that is weighted by the distribution in the corresponding youth sample. This enabled the observation of retention rates to be compared against a distribution that would be representative of the sample in question, as opposed to a theoretical null distribution, which could under report the prevalence of the RAE when assessing longitudinal retention (Delorme et al., 2010).

2.3 Results

We wanted to understand the relationship between athlete birth quarter and retention throughout the pathway, as a function of transitions between bodyweight categories and any changes in medal success. Therefore, athletes were categorised based on the characteristics of their individual pathway. This includes athletes maintaining or changing bodyweight categories (same weight vs weight change), athletes showing emerging versus disappearing medal success (late bloomers vs lost promise), and athletes consistently achieving or not achieving medal success (safe bets vs predictable underperformers).

2.3.1 Safe bets and predictable underperformers (same weight) (i.e., athletes who maintained weight category type and medal success)

Table 19 shows the distribution of the number of athletes retained in each pathway that maintained bodyweight classification and medal success by birth quarter, along with respective chi square analysis. The delta values show the difference between the observed and expected number that is based on the respective underlying retention rates. For female athletes, results show disproportionate birthdate distributions in the retention of athletes in the middleweight medallist to middleweight medallist ($X^2 = 31.21$, $p < 0.001$) and heavyweight medallist to heavyweight medallist ($X^2 = 16.01$, $p < 0.001$) pathways. Moreover, results show that proportionately more athletes born in Q4 were retained in the middleweight and heavyweight medallist pathways than those born in Q1. For males, disproportionate birthdate distributions were observed in the middleweight medallist to middleweight medallist ($X^2 = 32.42$, $p < 0.001$), heavyweight medallist to heavyweight medallist ($X^2 = 14.24$, $p < 0.01$), lightweight non-medallist to lightweight non-medallist ($X^2 = 12.85$, $p < 0.01$), middleweight non-medallist to middleweight non-medallist ($X^2 = 14.15$, $p < 0.01$), and heavyweight non-medallist to heavyweight non-medallist pathways ($X^2 = 14.79$, $p < 0.01$). In these pathways, a higher proportion of athletes born in the later quartiles than in the early quartiles were

retained. It is interesting to note the lack of retention effects in the lightweight medallist pathway, which is somewhat consistent with the interaction reported in experiment 1.

Table 19. Number of retained athletes that maintained weight category type and medallist status by birth quarter.

Sex	Pathway (Youth to Senior)	Q1	Q2	Q3	Q4	Total	χ^2	P
	Medallists to Medallists							
Female	Lightweight to Lightweight	10	4	7	6	27	6.81	0.078
	(Δ)	(-1)	(-3)	(+2)	(0)			
	Middleweight to Middleweight	10	22	13	15	60	31.21	<0.001
	(Δ)	(-19)	(+9)	(0)	(+6)			
	Heavyweight to Heavyweight	5	13	11	7	36	16.01	0.001
	(Δ)	(-5)	(+1)	(+1)	(+3)			
Male	Lightweight to Lightweight	11	5	6	9	31	0.72	0.869
	(Δ)	(-2)	(0)	(0)	(0)			
	Middleweight to Middleweight	16	10	15	16	57	32.42	<0.001
	(Δ)	(-17)	(-6)	(+4)	(+9)			
	Heavyweight to Heavyweight	11	11	9	8	39	14.24	0.003
	(Δ)	(-15)	(+1)	(+2)	(+4)			
	Non-Medallists to Non-Medallists							
Female	Lightweight to Lightweight	5	1	4	1	11	4.58	0.205
	(Δ)	(+1)	(-1)	(+1)	(-1)			
	Middleweight to Middleweight	13	11	6	10	40	2.83	0.419
	(Δ)	(+1)	(-1)	(-3)	(+3)			
	Heavyweight to Heavyweight	11	3	7	8	29	6.16	0.104
	(Δ)	(+1)	(-3)	(+2)	(+1)			
Male	Lightweight to Lightweight	5	3	12	6	26	12.85	0.005
	(Δ)	(-6)	(-3)	(+4)	(+3)			
	Middleweight to Middleweight	17	5	22	11	55	14.15	0.003
	(Δ)	(-10)	(-8)	(+11)	(+3)			
	Heavyweight to Heavyweight	2	12	9	5	28	14.79	0.002
	(Δ)	(-12)	(+3)	(+2)	(+2)			

Note: Δ represents the difference between the observed value and the expected theoretical value

2.3.2 Lost promise or late bloomers (same weight) (i.e., athletes who maintained weight category but changed medal status)

The data reported in table 20 represents the distribution by birth quarter of athletes that maintained bodyweight category but changed medal status between youth and senior.

This includes both athletes that transitioned from being medallists at youth to failing to medal in a senior competition (i.e., lost promise), as well as athletes who were not medallists at youth but went on to win a medal at senior level (i.e., late bloomers). Results show disproportionate distributions in the female lightweight medallist to lightweight non-medallist pathway ($X^2 = 10.78$, $p < 0.05$), the female heavyweight medallist to heavyweight non-medallist pathway ($X^2 = 46.63$, $p < 0.001$), the male heavyweight medallist to heavyweight non-medallist pathway ($X^2 = 12.78$, $p < 0.01$), and the male lightweight non-medallist to lightweight medallist pathway ($X^2 = 12.48$, $p < 0.01$). All disproportionate distributions show a higher proportion of Q4 athletes retained as the pathway progresses and an increased drop-out from Q1 athletes. Interestingly, the increased Q4 retention and Q1 dropout from non-medallists to medallists only occurred in the male lightweight category. All other pathways reported did not demonstrate significant distribution asymmetries ($p > 0.05$).

Table 6. Number of retained athletes that retained weight category status but changed medallist status by birth quarter.

Sex	Pathway (Youth to Senior)	Q1	Q2	Q3	Q4	Total	χ^2	P
	Medallist to Non-Medallist							
Female	Lightweight to Lightweight	3	6	4	6	19	10.78	0.013
	(Δ)	(-5)	(+1)	0	(+2)			
	Middleweight to Middleweight	9	7	8	5	29	3.5	0.32
	(Δ)	(-5)	(+1)	(+2)	(+1)			
	Heavyweight to Heavyweight	3	5	2	7	17	46.63	<0.001
	(Δ)	(-2)	(-1)	(-3)	(+5)			
Male	Lightweight to Lightweight	9	4	7	6	26	3.94	0.268
	(Δ)	(-2)	0	(+2)	(-1)			
	Middleweight to Middleweight	22	10	14	7	53	6.85	0.077
	(Δ)	(-6)	(-3)	(+5)	(+1)			
	Heavyweight to Heavyweight	13	13	7	8	41	12.78	0.005
	(Δ)	(-13)	(+3)	0	(+4)			
	Non-Medallist to Medallist							
Female	Lightweight to Lightweight	3	2	5	4	14	7.16	0.067
	(Δ)	(-2)	(-1)	(+1)	(+2)			
	Middleweight to Middleweight	2	4	5	3	14	3.04	0.385
	(Δ)	(-2)	0	(+2)	0			
	Heavyweight to Heavyweight	5	3	3	2	13	1.16	0.763

	(Δ)	(+1)	0	(+1)	(-1)			
Male	Lightweight to Lightweight	2	3	6	5	16	12.48	0.006
	(Δ)	(-5)	(-1)	(+1)	(+3)			
	Middleweight to Middleweight	13	5	0	7	25	5.16	0.161
	(Δ)	(+1)	(-1)	0	(+3)			
	Heavyweight to Heavyweight	3	3	5	2	13	4.57	0.206
	(Δ)	(-3)	(-1)	(+2)	(+1)			

Note: Δ represents the difference between the observed value and the expected theoretical value

2.3.3 Safe bets and predicted underperformance (weight change) (i.e., athletes who changed weight category type but maintained medal status)

Table 21 shows the distribution by birth quarter and chi square statistics for athletes that changed weight category but maintained medal status. Results show that distribution asymmetries in the female middleweight non-medallist to lightweight non-medallist pathway ($X^2 = 9.13$, $p < 0.05$), the male lightweight medallists to middleweight medallists ($X^2 = 16.27$, $p < 0.001$) and lightweight non-medallist to middleweight non-medallist ($X^2 = 13.83$, $p < 0.01$) pathways. In all pathways, over-representation was observed for athletes retained who were born in Q4.

Table 21. Number of retained athletes that maintained medallist status but changed weight category type by birth quarter

Sex	Pathway (Youth to Senior)	Q1	Q2	Q3	Q4	Total	χ^2	P
	Medallists to Medallists							
Female	Lightweight to Middleweight	1	0	1	1	3	3.72	0.293
	(Δ)	0	0	0	0			
	Middleweight to Lightweight	7	3	3	2	15	0.03	0.999
	(Δ)	0	0	0	0			
	Middleweight to Heavyweight	1	0	0	0	1	2.04	0.564
	(Δ)	(+1)	0	0	0			
	Heavyweight to Middleweight	3	3	2	2	10	2.65	0.448
	(Δ)	0	0	(-1)	(+1)			
Male	Lightweight to Middleweight	1	0	3	2	6	16.27	<0.001
	(Δ)	(-2)	0	(+2)	(+1)			
	Middleweight to Lightweight	6	2	2	1	11	0.34	0.953
	(Δ)	(+1)	(-1)	0	0			
	Middleweight to Heavyweight	2	1	0	2	5	5.23	0.155

	(Δ)	(-1)	0	0	(+1)			
	Heavyweight to Middleweight	4	3	1	2	10	3.21	0.361
	(Δ)	(-2)	(+1)	(-1)	(+1)			
	Non-Medallists to Non-Medallists							
Female	Lightweight to Middleweight	1	0	0	0	1	5.9	0.116
	(Δ)	(+1)	0	0	0			
	Middleweight to Lightweight	1	2	2	5	10	9.13	0.028
	(Δ)	(-2)	(-1)	0	(+3)			
	Heavyweight to Middleweight	1	2	2	0	5	6.28	0.099
	(Δ)	(-1)	(+1)	(+1)	0			
Male	Lightweight to Middleweight	0	1	0	3	4	13.83	0.003
	(Δ)	0	(-1)	0	(+2)			
	Middleweight to Lightweight	3	3	3	4	13	3.19	0.364
	(Δ)	(-4)	0	0	(+2)			
	Middleweight to Heavyweight	2	1	1	0	4	0.55	0.908
	(Δ)	0	0	0	0			
	Heavyweight to Middleweight	2	1	3	2	8	6.51	0.089
	(Δ)	(-2)	(-2)	(+1)	(+1)			

Note: Δ represents the difference between the observed value and the expected theoretical value

2.3.4 Lost promise or late bloomers (weight change) (i.e., athletes who changed weight category type and medallist status)

Lastly, the data shown in table 22 shows the distribution by birth quarter in the athletes that changed both bodyweight category type and medal status in the pathway from youth to senior. Results show disproportionate birthdate distributions in the female heavyweight medallist to middleweight non-medallist ($X^2 = 14.55$, $p < 0.01$), middleweight non-medallists to lightweight medallist ($X^2 = 11.35$, $p < 0.01$), heavyweight non-medallist to middleweight medallist ($X^2 = 13.09$, $p < 0.01$), and the male lightweight medallist to middleweight non-medallist ($X^2 = 7.96$, $p < 0.05$) pathways.

Table 22. Number of retained athletes that changed bodyweight category and medallist status by birth quarter

Sex	Pathway (Youth to Senior)	Q1	Q2	Q3	Q4	Total	χ^2	P
	Medallist to Non-Medallists							
Female	Middleweight to Lightweight	5	3	3	1	12	1.04	0.791

	(Δ)	(0)	(+1)	(+1)	(-1)	12		
	Heavyweight to Lightweight	0	0	1	0	1	5.07	0.167
	(Δ)	(0)	(0)	(+1)	(0)	1		
	Heavyweight to Middleweight	1	4	2	3	10	14.55	0.002
	(Δ)	(-2)	(+1)	(-1)	(+2)	10		
Male	Lightweight to Middleweight	0	1	0	0	1	7.96	0.047
	(Δ)	(0)	(+1)	(0)	(0)	1		
	Middleweight to Lightweight	3	3	1	0	7	2.89	0.409
	(Δ)	(0)	(+1)	(0)	(0)	7		
	Heavyweight to Lightweight	1	0	0	1	2	3.69	0.297
	(Δ)	(0)	(0)	(0)	(+1)	2		
	Heavyweight to Middleweight	4	1	2	2	9	3.64	0.304
	(Δ)	(-2)	(-1)	(0)	(+1)	9		
	Non-Medallists to Medallists							
Female	Middleweight to Lightweight	1	1	2	5	9	11.35	0.01
	(Δ)	(-2)	(-2)	(0)	(+3)	9		
	Middleweight to Heavyweight	1	0	0	0	1	3.1	0.376
	(Δ)	(+1)	(0)	(0)	(0)	1		
	Heavyweight to Middleweight	1	0	3	0	4	13.09	0.004
	(Δ)	(0)	(0)	(+2)	(0)	4		
Male	Lightweight to Middleweight	0	2	1	0	3	4.12	0.249
	(Δ)	(0)	(+1)	(0)	(0)	3		
	Middleweight to Lightweight	1	3	2	1	7	1.73	0.631
	(Δ)	(-3)	(+1)	(+1)	(0)	7		
	Middleweight to Heavyweight	2	4	2	1	9	1.87	0.599
	(Δ)	(-2)	(+2)	(0)	(0)	9		
	Heavyweight to Middleweight	0	0	2	0	2	4.55	0.208
	(Δ)	(0)	(0)	(+1)	(0)	2		

Note: Δ represents the difference between the observed value and the expected theoretical value

2.4 Discussion

To facilitate understanding of retention mechanisms underlying RAE findings in experiment 1, experiment 2 sought to investigate athlete retention as a function of birth quarter throughout the pathway. This was dependent on transitional characteristics of an athlete's individual pathway from youth to senior i.e., dependent on whether or not an athlete maintained or changed bodyweight category and subsequent medal success. This data provides valuable talent identification and selection information for practitioners regarding

the likelihood of Q1 athletes selected at youth level (based on maturational advantages), maintaining their success at later stages of the pathway. Furthermore, findings help us to understand what happens to Q4 athletes who remain in the system and whether they have the potential to become late bloomers. This has important implications for selection and development.

Whilst previous literature predicts increased selection (and thus, retention) of Q1 athletes, (i.e., the RAE; Barnsley et al., 1985), overall findings revealed a higher proportion of drop-out from Q1 athletes compared to Q4 athletes from youth to senior. This was supported by higher proportions of Q4 athletes retained in the pathway. This inconsistency is likely due to investigating athlete retention over time where previous research typically adopts cross-sectional approaches (see Cobley et al., 2009 for a review). This finding is also consistent with data observing reduced prevalence of RAE over time (e.g., Faber et al., 2019). Furthermore, and more interestingly, we see a higher proportion of Q4 athletes transitioning from being a non-medallist to a medallist compared with Q1 athletes as they progress from youth to senior. It is important to understand the mechanisms which allow Q4 athletes to achieve this.

In terms of medal success specifically, we see a higher proportion of male and female Q4 athletes in the middle and heavyweight categories maintaining bodyweight category as well as medal success i.e., our ‘safe bets’. Lightweight categories seem less vulnerable to the RAE (possibly because Q1 athletes exhibiting physical prowess as a result of biological maturation tend to end up in higher weight categories at youth level) and thus it may be that as a result, birth quarters have less influence on athlete retention in this weight category. Alternatively, this may be a result of Q1 athletes dropping out, as well as Q1 athletes transitioning down from middleweight to lightweight categories as they progress through the developmental stages. Similarly, we see a higher proportion of Q4 athletes moving from

lightweight to middleweight but retaining medal success. It is possible males are more able to sustain success when transitioning into higher weight categories compared to females. For those athletes who only emerge as medallists at the senior level, there is an increased prevalence of Q4 athletes achieving this for lightweight categories only (females verging on significance at 0.067). Finally, we see a similar prevalence of Q4 athletes who transition down weight categories and achieve medal success (females moving from middle to lightweight categories and males moving from heavy to middleweight categories).

3.1 Experiment 3

This increased prevalence of Q4 athletes only emerging as medallists at senior level, may be a consequence of a 'rocky road' or increased psychological determinants of expertise for relatively younger athletes (Collins & MacNamara, 2012; Hardy et al., 2017; Jones et al., 2018; Rees et al., 2016). To date, these potential psychological underpinnings of RAE have been hypothetical in nature and yet to be tested. Experiment 3 sought to investigate RAE in the context of key psychological characteristics, integral to expertise.

3.2 Methods

3.2.1 Participants and procedure

As part of a separate investigation into the longitudinal development of junior weightlifting athletes, 44 youth and junior weightlifting athletes (n males = 30, n females = 14, mean age ± SD = 15.6 ± 1.9) completed a battery of psychometric tests which evaluated a range of psychosocial attributes. These attributes included behaviours and attitudes towards training and competition such as achievement goal motivation, mastery and outcome focus, commitment to training, total preparation for competition, counterphobic attitude, and the relative importance of weightlifting in relation to other life choices. In addition, the psychometric battery also included trait personality measurements which have also been shown to discriminate super elite from elite performance (Hardy et al., 2017). These

personality traits were perfectionism, ruthlessness and selfishness, obsessiveness, and the big five personality traits: conscientiousness, extraversion, emotional stability, agreeableness, and openness to experience.

The psychometric battery consisted of 110 items, which were a formulation of existing psychometric inventories. Specifically, the battery consisted of the 2 x 2 achievement goal questionnaire for sport (AGQ-S) (Conroy et al., 2003), an early iteration of the athlete development formulation survey (ADFS; Langham Walsh et al [in preparation]), the importance of others in the self (Aron et al., 1992), the ten item personality inventory (TIPI; Gosling, Rentfrow, & Swann, 2003), the sport multidimensional perfectionism scale-2 (Sport-MPS-2; Gotwals & Dunn, 2009), the passion scale (Vallerand et al., 2003), and an adapted version of the Yale-brown obsessive-compulsive scale (Goodman et al., 1989), which was adapted to suit athlete obsessive thoughts and behaviours towards weightlifting.

In order to investigate the relationship between RAE and the aforementioned psychosocial attributes, the sample of athletes were grouped into half-year quartiles based on their month of birth (H1 vs H2), such that the athletes born between the 1st January and the 31st June were assigned to the first half-year quantile (H1), whilst the athletes born between 1st July and 31st December were assigned to the second half-year quartile (H2). This resulted in a H1 sample size of 19 (14 males, 5 females, mean ± SD = 15.5 ± 1.9), and a H2 sample size of 25 (16 males, 9 females, mean ± SD age = 15.7 ± 1.9).

3.2.2 Data Analysis

A Bayesian pattern recognition analysis was performed on the dataset to determine the subset of psychometric items that best classified birth-group membership. This analysis followed a two-part process, both of which made use of machine learning algorithms specifically designed for classification problems. The first part, termed feature selection, is a process that examines the relative importance of each item based on its respective predictive

validity. Depending on the algorithm used, each item in the dataset was either ranked by order of predictive power or was assigned a numerical value based on the number of iterations the algorithm had identified its importance. For this process, four separate algorithms were used to perform feature selection; namely the correlation attribute evaluator (CAE), the relief F attribute evaluator (Kira & Rendell, 1992), the support vector machine attribute evaluator (cf. Guyon et al., 2002), and the correlation-based feature selection (CFS; Hall, 1999) subset evaluator. As each algorithm used a slightly different logic process, and thus varied somewhat in the items they selected, the items that were ranked in the top 40th percentile of selected items across all four of the feature selection algorithms were ultimately selected for the next stage in the analysis.

The second part of the process, classification, utilized classification algorithms to assign each participant with an expected group membership based on their respective scores on the selected items. For this step, four commonly used classification algorithms were used, namely the naïve Bayes (cf. John & Langley, 1995), J48 decision tree (cf. Quinlan, 1993), support vector machine (cf. Platt, 1999) and K-nearest neighbours (Aha et al., 1991). This classification process was performed iteratively using a leave one out cross-validation procedure in order to minimise overfitting the findings to the data and thus preserving the generalisability of the resulting model. The classification rate (i.e. the number of athletes correctly classified versus the total sample size) for each algorithm reported in this study is therefore an average score for all of the iterations performed. The pattern recognition analysis was performed using the rWeka package in R (Hornik et al., 2009), which is a R interface for the WEKA machine learning statistical software package (Witten et al., 2011).

3.3 Results

The selected features and thus the resulting model are presented in table 23. A total of four constructs were selected from a potential of 26, namely: mastery approach, concern over

mistakes, emotional stability and openness to experience. Table 23 shows the group means for each item by each birthdate quantile. Athletes born in the first half of the year generally scored higher on emotional stability than those born in the second half of the year, whilst the inverse relationship was true for mastery approach, concern over mistakes, and openness to experience. This relationship is also depicted in figure 11.

Table 23. Group means (± standard deviations) for the items selected in the final psychosocial model

Construct	H1	H2
Mastery Approach	5.7 ± 1.0	6.0 ± 0.8
Concern over mistakes	2.4 ± 1.1	3.3 ± 1.6
Emotional stability	5.4 ± 1.4	4.6 ± 1.5
Openness to experience	4.8 ± 1.1	5.0 ± 0.9

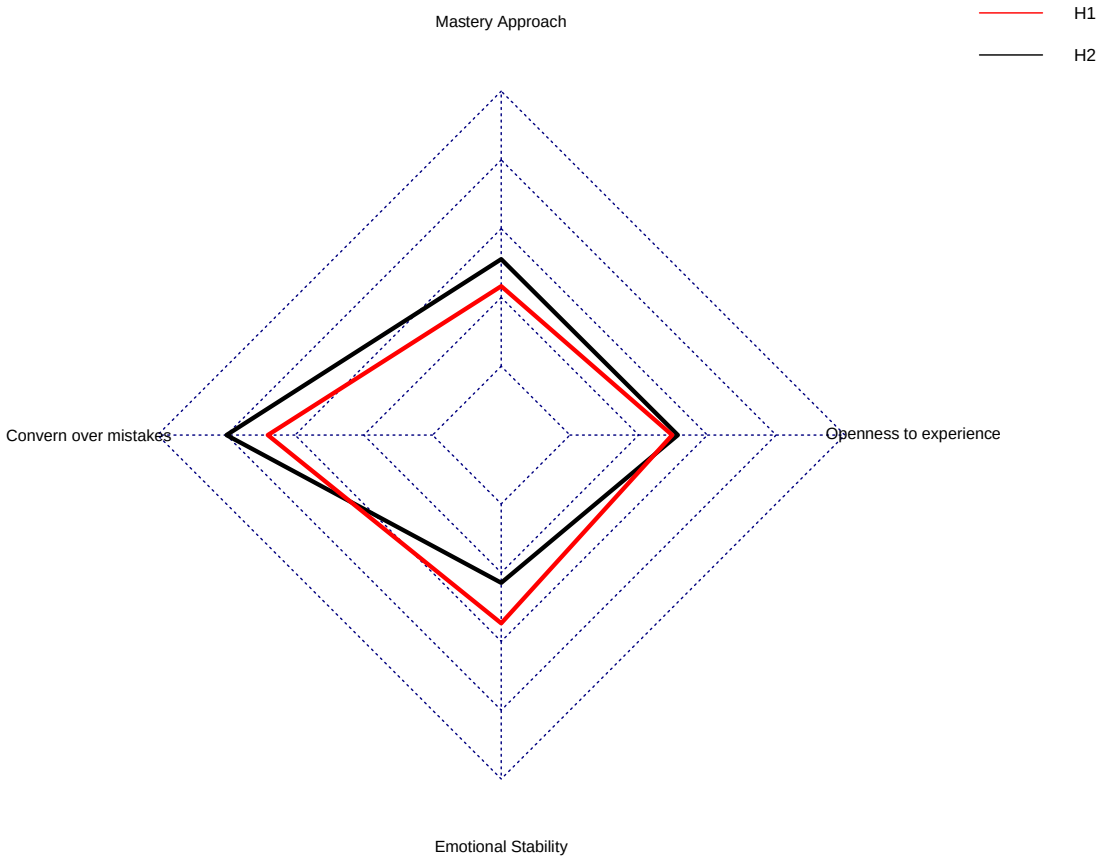

Figure 11. Radar plot depicting the relationships between birth halves and each of the four attributes in the model

Table 24 shows the results for the classification. Overall, the resulting model was able to successfully differentiate athlete birth halves with a 58.5% accuracy. The discrepancy between the sensitivity and specificity parameters (0.682 vs 0.473) also suggests that this model tended to correctly classify athletes in the second half of the year more successfully than athletes in the first. An average area under the curve of 0.57, which is generally used as measure of model efficacy, suggests that this model is generally a weak predictor of the relative age effect (moderate to strong models tend to range between 0.8 and 1; Obuchowski et al., 2004), although the model was still able to perform better than a completely naïve model (i.e. that which will return a 50% success rate). However, when the same models were

used to classify just the Q1 and Q4 sample, the model performance markedly improved (see parenthesized values in table 24). An area under the ROC curve of 0.756 for the Q1 vs Q4 sample suggests that the model was able to differentiate Q1 versus Q4 athletes with relatively better performance.

3.4 Discussion

Experiment 3 set out to determine if the relative age effect could account for differences in the psychosocial profiles of youth and junior weightlifting athletes. It was found that the relative age effect could be accounted for by a combination of motivational and personality characteristics, namely mastery approach, concern over mistakes, emotional stability, and openness to experience. Each construct will be discussed in the context of the relative age effect briefly below.

Table 24. Summary statistics for all four classification algorithms in H1 vs H2 (and Q1 vs Q4) classification

Classifier	Accuracy	Sensitivity	Specificity	Area under ROC curve
Naïve Bayes	51.30%	0.591	0.421	0.493
(Q1 vs Q4)	(59.00%)	(0.640)	(0.5)	(0.6)
Support Vector Machine	46.30%	0.636	0.263	0.45
(Q1 vs Q4)	(63.60%)	(0.714)	(0.5)	(0.66)
J48 Decision Tree	63.40%	0.727	0.526	0.617
(Q1 vs Q4)	(86.30%)	(0.824)	(1)	(0.863)
K-Nearest Neighbour	73.20%	0.773	0.684	0.728
(Q1 vs Q4)	(81.90%)	(0.813)	(0.833)	(0.9)
All Classifiers	58.50%	0.682	0.473	0.572
(Q1 vs Q4)	(72.70%)	(0.748)	(0.708)	(0.756)

Accuracy = Correctly classified observations / total number of observations. Sensitivity = 1 – false positive rate. Specificity = 1 – false negative rate. Area under ROC curve is a measure of model's ability to correctly distinguish the two groups. ROC = Receiver operating characteristic.

Mastery approach is an achievement motivation construct, which describes the attainment of competence that is based on becoming the best version of oneself, as opposed

to competence that is based on the self in comparison with others (Roberts et al., 2012). Individuals who are mastery approach motivated tend to strive to be better than their last performance, and generally show traits of adaptive achievement motivation, such as increased intrinsic motivation (Elliot & Harackiewicz, 1996) and absorption in the task (Cury et al., 2002). Mastery approach is also seen in the achievement motivation literature to be a distinctly different construct from performance approach (Conroy et al., 2003), the latter of which describes motivation towards the attainment of competence that is based on social comparisons with peers. In the context of the current study, this would seem to suggest that the relatively younger athletes tended to report higher scores for mastery approach perhaps as an indirect consequence of the physical disadvantages that being relatively younger poses. Moreover, perhaps being relatively younger led these athletes to be more focused on aspects of their own performance which require improvement, as opposed to being driven to outperform others in tasks in which they may have been biologically or psychologically disadvantaged from the outset. Furthermore, given the association between mastery approach and intrinsic motivation (Elliot & Harackiewicz, 1996), this form of motivation could have also encouraged these relatively younger athletes to stay in the sport until the physical disadvantages were no longer apparent.

Concern over mistakes describes a maladaptive form of perfectionism, which describes a tendency to react negatively to one's own performance (Dunn et al., 2006). Athletes exhibiting concern over mistakes tend to exhibit higher forms of cognitive and somatic anxiety (Hall et al., 1998), which could also account for the lower emotional stability observed in the relatively younger athletes in the current study. These concern over mistakes could have also occurred as a result of reactions to one's own performance being confounded with the biological disadvantages that a part of being relatively younger. Moreover, the potential long-term benefits of overcoming these concerns over mistakes, especially when

combined with adopting a mastery approach motivation, could have led to more resilience in these athletes. This proposition would indeed require further empirical support.

Emotional stability describes an individual's tendency to remain stable and balanced in a wide variety of situations (Thomas, Murphy, & Hardy, 1999). Both emotional stability and openness to experience form part of the big five personality traits. This trait could have perhaps emerged as a result of psychological maturation in the relatively older athletes. It is also worthy of note that the two items in the questionnaire that targeted this construct were 'I see myself as anxious, easily upset' and 'I see myself as calm, emotionally stable.' As the athletes in the questionnaire were asked about these questions in relation to their weightlifting performance, it could be very likely that the relatively older athletes could have answered these questions in relation to scenarios that were as a result of their psychological maturation, as well as being calmer in competitive scenarios in which they were biologically advantaged.

Openness to experience refers to the breadth and complexity of one's mental and experiential life (Costa et al., 1991). Openness to experience has also been associated with sensation seeking, and the tendency to seek varied experiences, which are often accompanied by heightened risk taking (e.g. Tok, 2011; Zuckerman, 2015). Given that weightlifting is a sport that offers quite intense emotional experiences during competition (i.e. the intense emotion associated with failing or succeeding a lift), the relatively younger athletes could have been attracted to the sport for the purposes of sensation seeking. This could also lead to increased attraction to the sport, beyond the obvious attraction of winning. This may not be as prevalent in the relatively older athletes, for whom attraction to the sport may be based on their physical advantages of being relatively older.

4. General Discussion

The aim of the present series of experiments was to test the relationship between RAE, gender, and bodyweight classification over progressing developmental stages of an

elite weightlifting pathway. Furthermore, we wanted to address this in the context of performance success over the course of the pathway, athlete retention between different developmental stages of the pathway, and any underlying psychological determinants of expertise. The multidisciplinary nature of this approach was in line with a developmental systems model (Wattie et al., 2014), proposing individual, task and environmental constraints in influencing RAE. The longitudinal design of the present studies also allowed us to consider the dynamic nature of these constraints over time. Overall findings revealed a typical RAE across all age groups and weight categories with the exception of female junior heavyweight and lightweight categories. Retention data suggests that despite this RAE, a higher relative proportion of Q4 athletes were retained in the pathway from youth to senior. Furthermore, we see a higher proportion of Q4 athletes transitioning from being a non-medallist to a medallist compared with Q1 athletes as they move through the pathway. These findings have several implications for coaches and practitioners within the pathway.

Researchers have previously hypothesised an elimination of RAE when environmental constraints in the form of weight categories are present (Delorme, 2014). The present findings highlight the robustness of the RAE despite these weight categories, which arguably limit the extent to which athletes of greater physical mass are competing directly against those of inferior mass.

A consequence of the cross-sectional approaches largely adopted throughout the RAE literature is limited understanding regarding an athlete's journey within a sporting system. The current findings tell us that it is the relatively younger athletes that are more likely to be retained from youth through to senior. It is also these particular athletes that are more likely to become late bloomers and medal at senior level. We propose that one reason for this is Q4 athletes exhibiting higher levels of some important psychological determinants of expertise. To the authors' knowledge, this is the first study to test this using an experimental design.

Results identified the following attributes as being integral to this process: mastery approach, concern over mistakes, emotional stability, and openness to experience. These characteristics have been recognised in the literature as being integral to expertise development (Hardy et al., 2017).

Practical recommendations of RAE remain largely under debate and warrant further scrutiny. However, it is widely accepted that practitioners should caution against selection criteria biased towards relatively older athletes (Hardy et al., 2017). What we are less sure on is methods such as bio-banding techniques (Cumming, Lloyd, Oliver, Eisenmann, & Malina, 2017), which may have unforeseen consequences and negate the development of the aforementioned psychological characteristics fostered when relatively younger athletes train and compete against their relatively older counterparts. In line with this, we would strongly recommend practitioners include psychometric testing within talent identification models. This will help identify athletes who may be less likely to stand out based on physical attributes, but who may possess important psychological characteristics that may increase their chances of becoming late bloomers. This can also be used as a development tool for athletes who may otherwise drop-out before transitioning to senior. Ultimately aiding retention of Q1 athletes that may not otherwise fulfil early promise.

In summary, the present series of studies provides a comprehensive test of developmental systems model (Wattie et al., 2014) in weightlifting, and reinforces the notion of considering RAE in the context of individual, task and environmental constraints. On the basis of this model, two athletes born on the same day will have very different developmental experiences. We would thus caution against practitioners applying a ‘one-size-fits-all’ approach to their athletes’ selection and development.

Chapter 6

General Discussion

The current thesis set out to explore the multidimensional influences on elite performance attainment in Olympic weightlifting. In chapters 2 through to 4, advanced data manipulation and machine learning algorithms were used to allow for a detailed examination of relationships in the multidimensional profile of the athlete that best determined elite performance attainment. The resulting findings were a vast selection of logical statements, underpinned by a theoretical framework, that described the holistic development of elite status. The findings from the current thesis, therefore, provides an evidence based holistic explanation of high-performance attainment in Olympic weightlifting. Moreover, sophisticated data handling techniques have provided an intelligent estimation of logic that can be applied by sports practitioners and policy makers. This logic is based on Bayesian principles of statistical inference and as such creates expectations about the development of high performance that is supported by historical observations. The findings from the thesis will be discussed in line with the framework outlined in chapter 1:

1. Demographics and familial sport participation

In general, the findings from the investigations in chapters 3 and 4 support the influence of wider environmental factors on the subsequent attainment of high performance. These findings centred around: (1) the parental involvement in sport, (2) the size of the homeplace throughout the early formative years (i.e. 6-12 years) and (3) the participation in sport at school, particularly during early formative years. For the first finding, athletes from both performance cohorts in both studies tended to have one or both parents participate in sport, and as such were likely at an increased exposure to sport participation as a result. These findings would reaffirm the importance of parental influence on subsequent sport participation, which would be in line with investigations reporting a direct influence of parents on both the child's initial participation (Stevenson, 1990) and long-term commitment to a sport (Yang, Telama, & Laakso, 1996). As will be discussed shortly, the data from both

chapter 3 and 4 support the notion of early sport sampling from as early as 6 years of age in both elite performance and non-elite athletes. It is reasonable, therefore, to expect that the athlete's exposure to early sport sampling was as a direct result of parental involvement in sport.

The current findings also suggest that the parental influence could also be accounted for in the selection of the homeplace throughout the athletes early formative years. Given that all athletes in both studies reported living with their parents throughout these early formative years, one could reasonably argue that the parent's decision to live in a town bigger than 7,000 inhabitants ultimately fosters the appropriate conditions for the child to flourish in their sport. The mechanisms that have been proposed for these conditions tend to be based on the town's infrastructure and the subsequent affordances for sport participation, such as the availability of sports facilities for both coach-led organised activities as well as unstructured playful activities (Hancock et al., 2018). Population density did not however appear to be a discriminator of elite performance in either study, which is contrary to the suggestions that it may be also be a better indicator of high-performance attainment than population size (Rossing, Stentoft, Flattum, Côté, & Karbing, 2018b). Rather, it would appear that absolute town size provides a better indication of elite-performance attainment in the current thesis. However, as will be discussed in the limitations of the thesis, the relatively small sample sizes used in the current thesis may not have been sufficient enough to reveal any influence of population density, especially as studies of the homeplace effect have typically derived at estimates from larger sample sizes (Hancock et al., 2018; Rossing et al., 2018b).

The final wider environmental influence on high performance attainment found in the current thesis is in relation to the participation in sport at school. This finding was only reported in the youth and junior athletes and as such may be limited to the development of junior performance rather than for long term performance at the senior level. As discussed in

chapter 4, schools based in larger towns may offer a wider range of sport provision for students to participate in, and as such may encourage athletes to engage in a wider array of sports training and competition. A sporting culture could also be developed through the interaction with physical education teachers and coaches whilst at school. These teachers may also encourage athletes with sporting potential to regularly engage in sport, which may in turn foster the benefits that early sport engagement entails, such as the development of motivational characteristics (Côté et al., 2003), preparation for future learning (Bransford & Schwartz, 1999) as well as the physiological adaptations that may be beneficial for later performance. The opportunities for higher levels of representation at school, such as national school competitions, may also develop the athlete's concept of themselves as sporting individuals, which could in turn encourage further investment into sport participation (Monsaas, 1985).

2. Sport participation history and weightlifting specific involvement

As previously mentioned, the findings from both chapters 3 and 4 also support the notion of early sport participation. A clear commonalty existed amongst both samples in both studies in relation to sport participation from as early as 6 years of age. This would thus appear to conform to the notion that later investment in sport at a later age emerges as a result of early sport participation (Côté et al., 2007). In relation to weightlifting specifically, early sport participation in other sports could also promote contextual introductions to weightlifting itself, as it is a sport that is often practiced in the strength and conditioning programmes of other sports, and athletes may already be exposed to the general aspects of weightlifting through their other sport. The differentiating factor of high-level performance in relation to sport participation, however, was in fact the overall number of sports involved throughout their early and middle formative years. Athletes who were generally higher performing athletes were involved in more sports from a younger age than non-elite athletes (i.e.

typically around 11 years of age). An interpretation of these findings could be twofold: firstly, higher performing athletes may have already been perceived to have the physical attributes for sport participation, and as such were encouraged to participate in more sports as a result of this general athleticism. Alternatively, athletes who participated in more sports from a younger age had developed the physical adaptations, such as strength, flexibility and power, that would benefit them for subsequent participation in their main sport. The answer could have also been a combination of these two cases. Specifically, as a result of better general athleticism, athletes could have been encouraged to participate in more sports, which would have in turn further developed the physical and psychological adaptations necessary for the subsequent attainment of high-level performance. Regardless, early sport participation does indeed appear to be an important factor in the development of high performance.

As discussed by Güllich et al. (2017), early sport participation is also proposed to better prepare the athletes to engage in future learning (Bransford & Schwartz, 1999). This concept could also relate to the transfer of learning, particularly from other sports with similar contextual properties. For instance, the involvement in an individual sport could also encourage the contextual factors about participating in an individual sport to be developed. This could be aspects such as mental preparation for competition, developing a routine for competition and training, and scheduling time outside of training for mental skills training and vicarious learning. All of these may already be in place prior to engagement in weightlifting, and as such these athletes may already inherit advantages both at the behavioural and the psychological level.

As well as general sport participation, participation in specific activities that are directly related to one's sport from an earlier age was also found to be an important determinant of high performance in attainment in both studies. In the context of weightlifting, this was specifically in relation to the volume of general strength and conditioning, as well as

that of flexibility and mobility training, which were usually reported to occur as a by-product of participation in other sports. In the data reported in the current thesis, substantial differences in these practice volumes typically appeared from around the age of 15, which would appear to suggest that elite performance does indeed begin to be developed from an early age, even if it does not involve the direct participation of the sport itself. This notion could also be a slightly alternative interpretation of the preparation for future learning concept previously discussed (Bransford & Schwartz, 1999; Güllich, 2017). Specifically, in addition to the psychological implications, preparation for future learning could also extend to the physiological systems. Moreover, progressive physical training, whether resistance or flexibility-based, should encourage long term adaptations through repeated cycles of overload and recovery. These long-term adaptations should then provide these athletes with the physiological base from which further increases in training volume and intensity can be tolerated.

From a theory of deliberate practice perspective, early bouts of physical training could be interpreted as the initial exposure to practice, from which a new performance level can be attained (Ericsson, 2014). Without this initial exposure, a new performance level may be more difficult to be achieved or may not be achieved at all. This also directly links to the finding that, in both studies, high performing athletes had accumulated higher volumes of weightlifting specific practice, which was apparent from as early as 15 years of age in the senior sample. This finding supports the fundamental tenets of the deliberate practice theory, which asserts that high volumes of deliberate practice is necessary for the attainment of elite performance (Ericsson et al., 1993). This is also in line with a large body of evidence supporting the theory of deliberate practice in sports performance (Rees et al., 2016).

However, an important distinction should be drawn with the interpretations of weightlifting and that of other sports. Specifically, as weightlifting is a sport in which athletes

acquire technical practice at a high percentage of maximal exertion, the rate at which high volumes of deliberate practice can be accumulated is limited by an individual's tolerance to the volume and intensity of training, as well as their rate of recovery and adaption. Thus, in order for high volumes of deliberate practice to be attained, training would need to be dispersed with periods of adequate rest and recovery. Weightlifting athletes are therefore in a constant trade-off between training and recovery in order to optimise the benefit of practice accumulation, and as such adopt periodized training programmes as a result (Bompa & Haff, 2009). Additionally, and as previously discussed, athletes may progressively begin to tolerate higher volumes of training the more experienced they become, which could ultimately expedite the rate at which practice is accumulated. This is also supported by the longitudinal evidence for higher volumes of practice accumulated reported in chapter 4. Therefore, early exposure to weightlifting specific practice should, in theory, better prepare athletes to tolerate higher volumes of practice later in development, especially when combined with early flexibility training and general strength and conditioning.

3. Physiological profile

The notion that elite athletes can tolerate a higher volume of practice also links directly to the findings that were centred around the physiological profile of the athlete. As discussed in chapter 1, differences at the level of the individual are proposed to differentiate the potential for performance, such that the upper and lower bounds of performance potential are largely genetically determined (Tucker & Collins, 2012). The finding from chapter 4 tends to support this contention, as differences in performance could be accounted for by physiological and anthropometrical characteristics, namely: (1) tibia length, (2) total arm to height ratio, (3) back and front squat to body mass ratio, (4) standing broad jump and countermovement jump performance, and (5) estimated peak power (Duncan et al., 2013).

This contention seems to be further supported when considering that anthropometrical characteristics (specifically tibia length and total arm to height ratio) may not necessarily be as influenced by training as much as other physiological characteristics, such as strength or power (Chatterjee, Das, & Chatterjee, 1999; Reilly, Bangsbo, & Franks, 2000). These findings also imply that the adaptations that occur from deliberate practice could also be genetically determined, thereby suggesting that athletes with an optimal physiological profile may benefit most from high volumes of deliberate practice. However, whilst the findings from the thesis supports the notion of an optimal physiological profile, they should not be interpreted outside of the general holistic profile of the athlete.

4. Psychosocial characteristics

The findings from the fourth chapter in the thesis also support the importance of psychosocial characteristics on the attainment of elite performance in weightlifting. These characteristics centre around the athlete's personality, motivation for achievement, and behaviours and attitudes towards their sport. Regarding the core characteristics of personality, high performing athletes tended to be conscientious, open minded, and extraverted individuals. As was highlighted in chapter 4, specific personality traits, especially conscientiousness, have been previously reported to be fundamental components of high achievers (Woodman et al., 2010). Extraversion was also discussed as being a component of an approach temperament (Elliot & Thrash, 2002), which may also be closely linked with the findings for approach-based achievement motivation also reported.

Some components of perfectionism were also associated with high performance attainment in chapter 4. Specifically, high performing athletes tended to be highly organized in relation to training and competition. They reported following routines in preparation for a competition, perhaps as a result of experience in other sports, and were generally highly

organised with their training. They also showed very low doubts about any actions they performed in relation to their sport.

High performing athletes in chapter 4 also reported to be highly motivated towards the attainment of both mastery, a task oriented form of achievement motivation, and the ego-oriented form, performance (Elliot & Harackiewicz, 1996). Both of these forms of achievement motivation have also been positively associated with objective sports performance, especially through the means of deliberate practice accumulation when presented in a structural equation model (Vallerand et al., 2008b). Additionally, the high performing athletes in chapter 4 maintained perspectives about their sport that fostered appropriate adaptive behaviours in relation to the achievement of high performance. More specifically, they showed a high passion for weightlifting, which perhaps placed their participation in the sport at a higher relative importance to other life commitments, such as work or other personal relationships. As a result, the high performing athletes also maintained a high degree of commitment to their sport, also as evidenced by the high volumes of practice accumulation. Finally, the athletes saw weightlifting as an avenue in which they could overcome intense emotions, and as such were drawn to the sport as an avenue to experience these intense emotions (Fenichel, 1939). This was also consistent with the findings reported in super elite British athletes (Hardy et al., 2017). Taken together, these findings would appear to support the contention that the psychological profile of athletes, which includes more stable personality traits, is indeed an important indicator of weightlifting performance.

5. Microstructure of practice

The findings from both chapters 3 and 4 in the thesis also reported the importance of the microstructure of practice. As discussed in the introduction to the thesis, whilst the volume of cumulative practice may provide a gross estimate of practice experience, examining the microstructure of practice may deepen the insights into the specific

development of athletes, and as such may provide a more detailed description of practice in the development of elite performance. The current thesis provides evidence in support of this notion. Specifically, the thesis has uncovered both commonalities as well as differentiating factors in relation to the microstructure of practice that fell into the following subthemes: (1) deliberate play versus deliberate practice, (2) mental skills training and vicarious learning, (3) conveying of information, (4) whole versus part practice, (5) constant versus varied practice, (6) specificity of practice, (7) focus of attention, (8) sources of feedback, and (9) constraints versus prescriptive coaching.

On the whole, the current thesis provides evidence that the microstructure of practice is generally optimised for the skill level of the athlete (Guadagnoli & Lee, 2004). The findings can be discussed in three distinct phases which coincide with the early, middle and later years of development (Balyi, 2001; Bloom, 1985). In the early years (typically at age 12 to 13), practice was generally identified as having very little developmental focus and was mainly centred around activities that were inherently enjoyable (i.e. deliberate play). As a result, very little mental skills training or vicarious learning were emphasized, although an occasional observation of more experienced athletes may have been of motivational benefit at this stage. Information conveyed to athletes was mainly conveyed verbally and through demonstrations. Practice was generally structured to allow athletes to perform both movements as a whole, with very little emphasis on the organisation of the movement. Practice conditions were kept fairly constant to encourage consistent performer-environment interactions. Moreover, very little of practice at this stage was specific to the demands of any competition.

In the middle phase (typically 13 to 15), practice became predominantly centred around the development of performance (i.e. deliberate practice). The technical aspects of each lift were emphasized in this phase, as the movements were broken down and practiced

in parts as well as whole. Information was still predominantly conveyed verbally, although other mediums such as video were used to allow the athletes to partake in the learning process. Practice was set up more so to meet the specific demands of competition, and also began to contain more varied practice conditions. The athletes also began to rely on their intrinsically derived sources of feedback, which was also accompanied by more mental skills training and vicarious experiences outside of their training.

In the later phase (typically 16 to 19), practice was predominantly if not completely deliberate practice. Both the snatch and clean and jerk were practiced as parts and as well as whole, although more emphasis was placed on the whole movement as the movements should have been well organised by this stage. Information remained to be conveyed verbally and with demonstrations, although more emphasis was placed on video feedback. Practice conditions contained a high degree of variety in terms of performer environment interactions. Athletes also reported to be self-sufficient in terms of their intrinsically derived feedback. They were also voluntarily completing a high volume of mental rehearsal and watching other athletes vicariously for the benefit of their own learning.

These findings demonstrated the need for the microstructure of practice to contain clear progression throughout the pathway. As was clearly apparent in the data, each phase of development distinctly prepared the athletes for the later phases, both in terms of motor skill acquisition and conveying of information. This detailed progression for the microstructure of practice also provide empirical support for the tenets of the challenge point framework, which states that practice conditions should provide learners with the optimal challenge point that is most appropriate for their level of skill (Guadagnoli & Lee, 2004).

6. Competitive milestones and pathway challenge

Chapter 2 provided a holistic analysis of the performance pathway for Olympic weightlifting in Britain. This analysis detailed gender specific performance and competitive

experience related objectives at each age in the pathway. The performance related parameters specified the approximate distance from the population norm elite athletes were expected to be, whilst estimates of the likelihood of elite performance attainment based on performance being above these parameters were also provided. Additionally, specific target competitions were also determined that were based on their capacity to discriminate elite athletes from their non-elite counterparts. On some occasions, specific placings at each competition were also shown to significantly discriminate high performing athletes for their low performing counterparts.

Moreover, the resulting models were subsequently used to profile athletes on the basis of their likelihood of elite performance in both chapters 2 and 3. The use of these algorithms differed from the classification approaches used in past talent identification research (Güllich et al., 2019; Johnston et al., 2018). Specifically, the likelihood of elite status was determined not only by the achievement of high performance, but also by the historic competitive experience, such as competing in, and in some cases winning a medal in, specific competitions along the pathway. As such, the athlete's profile was assessed not just on the basis of competition performance itself, but also on their accomplishments and acquired experience, thus forming a more rounded perspective on elite status attainment throughout the pathway.

The level of challenge that each level of representation along the pathway presented to the performer was also moderately important features in the pathway to elite senior performance. Elite athletes reported that early exposure to the highest level of domestic representation did not impose a high degree of challenge to the athlete, which ultimately enabled them to become accustomed to competing regularly on the domestic stage. It was not until their highest level of international representation did they begin to experience both technical and psychological challenges that were unique to the international stage. In line

with the rocky roads perspective of talent development (Collins & MacNamara, 2012), these challenging experiences become beneficial to the athlete in the long term, particularly when they are interspersed with periods of adjustment (Dienstbier, 1989). On the whole, these findings suggest that early international exposure will better prepare athletes for the demands of competing internationally. This is also supported by the findings in the pathway analyses, which suggests that exposure to an international developmental competition by the u15 age group was a significant predictor of elite status at senior.

7. Normative data

Throughout the thesis, various linear estimates of normative data were also calculated which provided a population estimate for various performance-based parameters throughout development (see appendices for model coefficients). These parameters served as useful metrics to map performance indicators across multiple stages of the pathway. The logical rules which were developed from most of the analyses in chapters 2 through to 4 were also based on this normative data. These may serve as useful diagnostics tools for future talent development procedures in providing a national reference point across a range of attributes.

8. Relative age effect

Whilst adopting the underlying theory of the developmental systems model (Wattie, Schorer, & Baker, 2014b), the study in chapter 5 also explored the prevalence of the relative age effect in an entire population of elite weightlifting athletes. The interaction between the relative age effect, age group, and bodyweight category had influenced medallist achievement thereby supporting the proposed interaction of the performer, environment, and task constraints in accounting for the relative age effect. Interestingly, relatively younger athletes appeared to be almost equally likely to win a medal than relatively older athletes in the lightest weight categories, which suggests that these categories had somewhat controlled for the influence of physical advantage. This was also shown in the lack of relative age effect

influence on the long-term retention of athletes in lighter weight categories. This was not as evident in middleweight and heavyweight categories, as proportionately less Q1 athletes remained in the pathway from youth to senior, even after winning a medal at youth. These findings provide quasi-experimental evidence to support the potential long-term implications of the false physical advantages that are pronounced in the relative age effect.

Additionally, to the first of the authors knowledge, experiment 3 from chapter 5 was the first investigation to explore the psychosocial characteristics of the relative age effect. Machine learning (or pattern recognition) was deployed to produce a model of four psychosocial constructs that best differentiated birth quarter. These attributes were mastery approach, concern over mistakes, openness to experience and emotional stability. It was interesting to note that three of the four characteristics were typically personality trait measures, which emphasises the long-term psychosocial implications of the relative age effect. As discussed in chapter 5, these findings emphasized the need for talent identifications systems to use psychometric testing as part of their procedures in order to profile the characteristics of athletes who may be influenced by the relative age effect.

Limitations

Whilst the thesis has aimed to provide comprehensive examinations in its empirical approach, there are some limitations to the approach used in the current thesis which are noteworthy. The first is in relation to the size of the samples for the studies in chapters 3 and 4. In order to establish a holistic profile of all athletes in the study, statistical power was indeed sacrificed for the sake of detail. This was particularly true of the very small high performing sample reported in chapter 4 (6 high performing versus 23 low performing). Future research should therefore endeavour to reproduce some of the relationships reported in the thesis with a larger sample size.

Similarly, as the holistic profile of the athletes in both studies included more than 300 unique attributes which were individually collected, much of the potential depth in the data was sacrificed for breadth. In other words, some of the more complex relationships between some of the variables and high performance may have been somewhat overlooked in both studies in order to report as many relationships as possible. This could also apply to the quality of data collected from each athlete. Whilst the testing protocol procedures were adhered to as strictly as possible, performing this volume of tests would have likely resulted in measurement error in some instances. Additionally, as many participants were asked to recall a wide range of information, they may have not been able to accurately recall all information without introducing some form of error.

Additionally, at the technical level, all logical attributes reported in all analyses made use of the best estimate of the underlying parameter. Whilst this allowed for a simple application of logic (i.e. whether or not the athlete fell above or below the parameter) on a broad range of attributes, these were not the only parameters that could have been applied. In order words, there were some instances in which the odds ratio analyses selected another parameter which contained the same predictive power as the final chosen parameter. This was particularly prevalent for estimates of practice volumes. Policymakers should therefore exercise caution if aiming to apply the exact parameters in field-based applications. It would be recommended in some cases to use the parameters as general approximations.

Finally, in relation to the pathway analyses, the specified performance related parameters typically identify a minimum attainable parameter, which may therefore struggle to differentiate athletes who are performing well beyond the specific parameters. Policy makers and practitioners should therefore also exercise discretion if applying any of the findings in pathway monitoring procedures.

Summary timeline

A summary timeline of all findings from chapters 2 through to 4 are shown in table 25. This table presents a detailed overview of the development of high performance in weightlifting, which is supported by the evidence discussed above. As can be seen, specific parameters across multiple disciplines are presented chronologically starting from the age of 6 through to age 23. The findings that were explicitly reported to discriminate performance are highlighted in bold text, whilst the non-discriminative features are italicised. Moreover, elements of the timeline are generalised across genders. Caution should therefore be exercised when applying this timeline to specific cases.

Future research directions

The current thesis sought to contribute to the existing body of research that have adopted a multidimensional approach to exploring the development of talent (Güllich et al., 2019; Jones et al., 2019). Moreover, the thesis also sought to add to the methodological framework in this field of research by introducing the concept of advanced data processing through open source statistical software packages, such as R, or Python. It would therefore be greatly encouraged that future research should continue to expand this body of research in order to uncover the multidimensional relationships that characterize the development of sports performance.

A particular emphasis for future research in this field would be to continue to utilize machine learning within their investigations. As discussed throughout the thesis, machine learning enables for a multitude of variables to be examined simultaneously, and as such the relative importance of features can be determined. This approach will allow for domain specific conceptualisations of talent development that are underpinned by existing theoretical frameworks to emerge. Moreover, in order for machine learning to be robust in its application, emerging models of talent development must continually be *trained* with new

data (Chollet, 2018), which therefore emphasizes the need for more research with multidimensional datasets to continue to contribute to this body of research.

Adopting this multifaceted approach with machine learning methodologies would also require very robust classification criteria. This is particularly true as resulting models can change drastically as a result of a change in the criteria on which they are trained. The current thesis has adopted an algorithmic approach to this problem, by establishing a set of attributes form which the likelihood of elite status can be determined (see table 6 from chapter 2). This approach does however require extensive historic data from which to form these algorithms can be trained, and thus would generally not be applicable to all fields. Should research continue using classification methods of machine learning, then a framework from which determining the criteria for elite performance should be established.

Finally, as discussed in chapter 2, machine learning generally follows a 2-part process: feature selection followed by classification. The first process, feature selection, filters the multidimensional dataset to a core set of features to be selected which contain the most predictive power, in turn reducing the risk of a type I error (Güllich et al., 2019; Kuncheva & Rodríguez, 2018). However, caution should be employed when discarding the unselected features as unimportant in this process, particularly when using small sample sizes, as these features may still contain theoretical relevance. As such, the *relative* importance of all features in the data should be retained in any analyses and should continue to be driven by overarching theoretical frameworks.

Thesis conclusion

In summary, the data from the current thesis has extended the framework of talent development to the domain specific area of sporting expertise, Olympic weightlifting. The thesis characterizes the development of high performance in weightlifting as a construct which emerges from a specific set of antecedents, which is then fostered by early exposure to

environments that encourage the emergence of desired motivational and physiological traits, and is then honed with extensive exposure to conditions of practice that promote robust performance in competition.

Table 25. Summary timeline consolidating all findings from chapters 2 to 4 of the thesis in chronological order

Age	Pre early development	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Demographics and familial sport participation	**Parental involvement in sport**	**Population of longest residing homeplace over 6,392 pop**																	
		School main place for sport participation																	
Sport participation and weightlifting specific involvement																			
Number of sports sampled		**1 or more sport**				**2-3 sports**						**No more than 2 sports**		**1 sport**					
Flex/Mob Training (per week)						**10 min**	**10 min**	**50 min**	**55 min**	**1 hr 30 m**	**1 hr 40m**	**2 hours**							
General Strength & Cond (per week)					**25 min**	**30 min**	*30 min*	*30 min*	*1hr 20m*	*2 hours*	**2hr 10m**	**2.5 hours**							
Weightlifting Technical (hours/week)							*<1 hour*	*< 1 hour*	**2 hours**	**4 hr 30 m**	*6 hr 30m*	*9 hr 10m*	*9 hr 10m*	*10 hr 25m*	*>11 hours*				
Microstructure of practice																			
Deliberate Play versus Practice							*80% Play / 20% Practice*		**20% Play / 80% Practice**			*<5% Play / 95% Practice*							
Mental skills							*<1 hour*	*<1 hour*	**5-10 hours**		**10-15 hours**								
Vicarious Experiences							*<1 hour*	*<1 hour*	**1-5 hours**		**5-10 hours**								
Information conveyed							*70% Verbal / 30% Demo*		**60% Verbal / <30% Demo / 10% Video**			**70% Verbal / <10% Demo / 20% Video**							
Snatch whole/part practice							*80% Whole / 20% Part*		*35% Whole / 65% Part*			*40% Whole / 60% Part*							
Clean & Jerk whole/part practice							*80% Whole / 20% Part*		**25% Whole/ 75% Part**			**30% Whole / 70% Part**							
Constant/Varied practice conditions							*95% constant / <5% varied*		**75% Constant/ 25% Varied**			**70% Constant/ > 30% varied**							

Age	Pre early development	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Anxiety specific practice							*<1% Anxiety specific*		**35% Anxiety specific**			*>10% Anxiety specific*							
Context specificity practice							*<5% Context specific*		**>40% Context specific**			*>10% Context specific*							
Focus of attention							*50% Internal / 50% External*												
Sources of feedback							*95% Extrinsic / 5% Intrinsic*		**75% Extrinsic / 25% Intrinsic**			**60% Extrinsic / 40% intrinsic**							
Prescriptive coaching									**15% Constraints / 85% prescriptive**			**30% Constraints / 70% Prescriptive**							
Psychosocial Development																			
Achievement motivation									**High Mastery Approach**										
									High Performance Approach										
Behaviours and Attitudes									**High commitment to training**										
									High Counterphobic Attitude										
									Moderate to high relative importance of sport										
									High Passion for sport										
Athlete Personality									**High conscientious**										
									Moderate to high open mindedness										
									High extraversion										
									Perfectionism: Low doubts about actions										
									Perfectionism: High organization										
Key Physiological and Anthropometric Indicators																			
Tibia Length									**Tibia height >3.8cm above norm**										
Total arm to height ratio									**Total Arm to height ratio above norm**										
Peak power estimate (Duncan)									**Peak power estimate >225W above norm**										

Age	Pre early development	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Standing broad jump distance									**Standing broad jump distance >11cm above norm**										
Countermovement jump height									**Countermovement jump height >1.5cm above normative**										
Back Squat to body mass ratio									**Back squat to body mass ratio >1.02 above norm**										
Front Squat to body mass ratio									**Front squat to body mass ratio >0.48 above norm**										
Overhead Squat Torso Angle									**Overhead Squat Torso Angle more than 66 degrees**										
Pathway Challenge Indicators																			
Domestic Psychological						*Low*					**Low to moderate**			*Moderate*					
Domestic Technical						*Low*		*Low to moderate*			Moderate								
International Psychological						*Low to moderate*		*Moderate*			**Moderate to High**								
International Technical						*Low to moderate*		*Moderate*			*Moderate to High*								

Key Pathway Indicators (Women)	U13	U15	U17	U20	U23
Average Total		**Total above norm**	**Total >7kg above norm**	**Total > 6.5kg above norm**	**Total > 11kg above norm**
Average Snatch 1st attempt		*Sn1 above norm*	*Sn1 >3.5kg above norm*	**Sn1 >4kg above norm**	**Sn1 >4kg above norm**
Average Clean & Jerk 1st attempt		**CJ1 >1kg above norm**	**CJ1 >4.5kg above norm**	**CJ1 >3.5kg above norm**	**CJ1 >6.5kg above norm**
Number of competitions		*5 events*	**11 events**	**12 events**	**11 events**
Highest Domestic Competition		*British Junior*	*British Senior*	**British Senior 2 times**	**British Senior 3 times**

Age	Pre early development	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Highest Domestic Comp Rank														**Gold at British Senior**			**Gold at British Senior**		
Highest International Competition										**Int'l Develop Junior**		**Continental Youth**		**World Senior**			**World Senior**		

Key Pathway Indicators (Men)	U13	U15	U17	U20	U23
Average Total	**Total >3kg above norm**	**Total >3.5kg above norm**	**Total >7kg above norm**	**Total >27.5kg above nor**	**Total >23.5kg above norm**
Average Snatch 1st attempt	**Sn1 above norm**	**Sn1 >1kg above norm**	**Sn1 >8kg above norm**	**Sn1 >8kg above norm**	**Sn1 >11kg above norm**
Average Clean & Jerk 1st attempt	**CJ1 >1.5kg above norm**	**CJ1 >1kg above norm**	**CJ1 >3kg above norm**	**CJ1 >9.5kg above norm**	**CJ1 >12kg above norm**
Number of competitions	**2 events**	**5 events**	**6 events**	**10 events**	**8 events**
Highest Domestic Competition	**British Youth**	**British Junior**	*British Junior*	**British Senior**	**British Senior 2 times**
Highest Domestic Comp Rank	**4th at British Youth**	**4th at British Youth**	**Silver at British Junior**	**4th at British Senior**	**Silver at British Senior**
Highest International Competition		**Int'l Develop Junior**		**World Junior**	**World Senior**

Normative Physical Indicators (Women)	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Back squat to body mass ratio	0.54	0.67	0.80	0.92	1.05	1.18	1.31	1.43	1.56	1.69	1.82	1.95	2.07	2.20
Front squat to body mass ratio	0.43	0.55	0.66	0.77	0.88	0.99	1.10	1.22	1.33	1.44	1.55	1.66	1.78	1.89
Standing Broad Jump Distance (cm)	145	150	155	160	165	170	175	179	184	189	194	199	204	
Countermovement Jump Height (cm)	28	30	33	35	38	40	43	45	48	50	53	56	58	
Estimated Peak Power (W; Duncan)	1676	1879	2081	2284	2487	2690	2892	3095	3298	3501	3703	3906	4109	4312
Tibia Length (cm)	38.7	38.6	38.6	38.5	38.5	38.4	38.4	38.3	38.3	38.2	38.2	38.1	38.1	38.0

Age	Pre early development	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
§																			
Total arm to height ratio						0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.32	0.32	0.32	0.32
Normative Physical Indicators (Men)																			
Back squat to body mass ratio						0.47	0.67	0.87	1.08	1.28	1.48	1.68	1.88	2.08	2.29	2.49			
Front squat to body mass ratio						0.42	0.58	0.74	0.90	1.05	1.21	1.37	1.53	1.68	1.84	2.00	2.16	2.32	2.47
Standing Broad Jump Distance						131	145	159	172	186	200	214	227	241	255	269	282		
Countermovement Jump Height						22	27	32	37	42	47	52	57	62	67	72	77		
Estimated Peak Power (Duncan)						882	1338	1793	2248	2703	3158	3614	4069	4524	4979	5435	5890		
Tibia Length						37.8	38.3	38.8	39.3	39.9	40.4	40.9	41.4	42.0	42.5	43.0	43.5	44.1	44.6
Total arm to height ratio						0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.33	0.33	0.33	0.33
Normative Total values by Bodyweight class (Women)																			
40						32	41	48	56	62	81	96	109	119	126	132	136	138	140
45						38	46	54	62	68	87	102	115	124	132	138	142	144	146
49						42	51	59	66	73	91	107	119	129	136	142	146	149	150
55						48	57	65	72	79	97	113	125	135	143	148	152	155	156
59						52	61	69	76	83	101	117	129	139	146	152	156	159	160
64						57	66	73	81	87	106	121	134	144	151	157	161	163	165
71						64	72	80	87	94	113	128	140	150	158	163	167	170	172
76						68	77	85	92	99	117	133	145	155	162	168	172	175	176
81						73	82	90	97	104	122	138	150	160	167	173	177	180	181
87						80	88	96	103	110	129	144	156	166	174	179	183	186	188
87+						89	98	105	113	119	138	153	166	176	183	189	193	195	197

Age	Pre early development	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Normative Total values by Bodyweight class (Men)																			
49						37	52	65	88	108	125	141	154	166	175	182	188	192	195
55						49	63	77	99	119	137	153	166	177	186	194	200	204	206
61						60	75	88	111	131	149	164	177	189	198	205	211	215	218
67						72	86	99	122	142	160	175	189	200	209	217	222	227	229
73						83	97	111	133	153	171	186	200	211	220	228	234	238	240
81						97	111	125	147	168	185	201	214	225	235	242	248	252	255
89						111	125	138	161	181	199	214	228	239	248	256	261	266	268
96						122	136	149	172	192	210	225	239	250	259	267	272	277	279
102						130	145	158	181	201	219	234	248	259	268	276	281	285	288
102+						138	153	166	189	209	227	242	256	267	276	284	289	294	296
Normative Sn1 values by Bodyweight class (Women)																			
40						10	14	17	21	23	32	39	45	49	53	56	58	59	60
45						13	16	20	23	26	34	41	47	52	55	58	60	61	62
49						14	18	22	25	28	36	43	49	54	57	60	62	63	64
55						17	21	24	27	30	39	46	52	56	60	62	64	66	66
59						18	22	26	29	32	40	47	53	58	61	64	66	67	68
64						20	24	28	31	34	42	49	55	60	63	66	68	69	70
71						23	27	30	33	36	45	52	58	62	66	69	70	72	72
76						25	29	32	35	38	47	54	60	64	68	70	72	74	74
81						27	30	34	37	40	49	56	61	66	70	72	74	75	76
87						29	33	36	40	42	51	58	64	68	72	75	77	78	79
87+						33	36	40	43	46	55	62	67	72	76	78	80	81	82
Normative Sn1 values by Bodyweight class (Men)																			

Age	Pre early development	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
49						10	17	23	34	43	51	58	64	70	74	77	80	81	82
55						15	22	28	38	48	56	63	69	74	79	82	84	86	87
61						20	26	33	43	53	61	68	74	79	83	87	89	91	92
67						25	31	37	48	57	66	73	79	84	88	92	94	96	97
73						29	36	42	53	62	70	78	84	89	93	96	99	101	102
81						36	42	49	59	68	77	84	90	95	99	103	105	107	108
89						42	48	55	65	74	83	90	96	101	105	109	111	113	114
96						47	53	59	70	79	88	95	101	106	110	114	116	118	119
102						51	57	63	74	83	92	99	105	110	114	118	120	122	123
102+						54	61	67	78	87	95	102	109	114	118	121	124	125	126
Normative CJ1 values by Bodyweight class (Women)																			
40						15	20	24	28	32	43	51	58	64	68	71	74	76	77
45						18	23	27	31	35	45	54	61	66	71	74	77	78	79
49						20	25	29	33	37	47	56	63	68	73	76	79	80	81
55						23	27	32	36	40	50	59	66	71	76	79	81	83	84
59						24	29	34	38	42	52	60	67	73	78	81	83	85	86
64						27	32	36	40	44	54	63	70	75	80	83	86	87	88
71						30	35	39	43	47	58	66	73	79	83	86	89	91	92
76						33	37	42	46	50	60	69	76	81	86	89	91	93	94
81						35	40	45	49	53	63	71	78	84	88	92	94	96	97
87						39	44	48	52	56	66	75	82	88	92	95	98	100	101
Normative CJ1 values by Bodyweight class (Men)																			
49						16	24	32	44	55	65	74	81	87	92	96	99	101	103
55						22	30	38	50	61	71	80	87	93	98	102	105	107	109
61						28	36	44	56	67	77	86	93	99	104	108	111	113	115
67						34	42	50	62	73	83	92	99	105	110	114	117	119	121

Age	Pre early development	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
73						40	48	56	68	79	89	97	105	111	116	120	123	125	127
81						48	56	63	76	87	97	105	112	118	124	128	131	133	134
89						55	63	70	83	94	104	112	120	126	131	135	138	140	141
96						61	69	76	89	100	110	118	125	132	137	141	144	146	147
102						65	74	81	93	105	114	123	130	136	141	145	148	151	152
102+						70	78	85	98	109	119	127	134	141	146	150	153	155	156

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Supplementary Information: Chapter 2

A state-of-the-art analysis of the British performance pathway in Olympic weightlifting

The aim of this supplementary document is to present:

1. A breakdown of the protocols used in the methods
2. The model coefficients for all linear estimations of all normative data used in pathway analyses
3. A full breakdown of the odds ratio estimations for each logical attribute in the pathway analyses

Protocols used in chapter 4.

A total of 648 variables were collected which included a combination of variables that explored the following disciplines: (1) Demographics and family information, (2) athlete physiological profile, (3) athlete psychosocial profile, (4) sporting history and weightlifting specific involvement, and (5) Weightlifting specific practice. The protocols deployed for the collection of these variables are discussed below:

1. Demographics and family information

1.1 Population density of homeplace throughout formative years

As part of the athlete development survey, athletes were asked to list the name of the town in which they lived every year starting from the age of 6 to their current age. This allowed for the profiling of the population density of each town lived in at each age, as well as more global homeplace profiling, such as the number of times relocated throughout developmental years.

Population density information for each town was extracted from www.citypopulation.de, which is a database containing global population census for all cities starting from 1991, and at 10 year intervals to 2011. The database contained information about the town size (in km^2), population, and population density (population per km^2) for all local authority districts and communities in Wales and across the United Kingdom. In order to gain an appropriate estimate of town population and population density for each athlete, population data for each town was obtained from the closest corresponding census to the age of the athlete (e.g. the 2001 census was used for athletes born in 1995 and who were 6 years of age by 2001, which was then changed to the 2011 cencus for towns listed from 16 years of age).

In order to appropriately profile athletes homeplace throughout their development, the population density for the homeplace in which the athlete lived the longest between the ages of 6-12 years and 13-15 years were included in the analysis. Additionally, the number of times relocated throughout years were also included.

1.2 Schooling

Participants were also asked to list the name of the school in which they had attended each year starting from the age of 6. They were also asked to indicate (by circling ‘Yes’ or ‘No’), to whether or not each school they has listed was the main place in which they practiced all of their sport. Further information about each school was then gathered using a simple web search about each school. Specifically, each school was classified as either state or private school from the information gathered on each school’s website. Additionally, the address of each school the athlete attended whilst involved in weightlifting was also obtained in order to estimate the approximate distance between the school and the athletes weightlifting club.

1.3 Familial Sport Participation

Participants were asked whether or not their parents/guardians and siblings were involved in sport. This included coaching and participating in sport, and to what level they participated (club, national, international and/or elite). Participants were also asked to list the names, gender, and date of births of each siblings. This allowed for information about relative age to each sibling and whether or not each sibling was the same sex to be obtained, as these factors have been shown to foster the development of elite performance (insert citation).

1.4 Relative Age

As athletes were asked to provide their date of births in the development survey, athlete birth quarters were assigned to each athlete in order to determine any potential relative age influences on the subsequent development of the athletes. Birth quarters were assigned based on the calendar year, with quarter 1 assignment starting from the 1st January to the 31st March, quarter 2 assignment starting from 1st April to 31st June, quarter 3 assignment starting from 1st July to 31st September, and quarter 4 assignment starting from 1st October to 31st December. These quarters were also in line with the cut off dates between age groups used by the both the European and international weightlifting federation.

Additionally, as all of the athletes in the current study were in full time education in Wales, in which the cut off dates between school years start from September and end in august, the potential for relative age effects could have existed at the level of school sport participation, which could have influenced subsequent development in weightlifting. It was therefore decided to also assign athletes with birth quarters that were based on the academic year. Specifically, school birth quarters were assigned using the same 3-month window as the calendar birth quarters, but with quarter 1 assignment starting from 1st September (as opposed to 1st January).

2. Athlete Physiological profile

Athletes were periodically monitored using a battery of physical and performance-based tests in order to assess the relative importance of athletes physiological profile on weightlifting development. This testing battery was primarily designed to target the physical and skill-based domains most pertinent to Weightlifting performance. These domains are maximum dynamic force production, handgrip strength, body composition and anthropometrics, slow stretch-shortening cycle utilization, squat mobility and trunk control. A summary of the domains and the associated variables can be seen in figure 1.

2.1 Maximum dynamic force production

As one of the fundamental tenets of weightlifting performance is based on dynamic force production, it was decided to assess dynamic force production using estimates of the 1 repetition maximum for the back squat and the front squat. As these measures are already attained at regular intervals throughout the athletes training programme, athletes were asked to report their 1RM for each lift during the testing session. These maximums were then confirmed by the athlete's coaches.

2.2 Handgrip strength

Athlete's handgrip strength was monitored using a handgrip dynamometer. Hangrip assessment was tested under the standard regulations for testing handgrip dynamometer strength (TNC-CDAAR, 2003). Specifically, once the handgrip was adjusted to match the hand size, athletes were asked to the hold the handgrip dynamometer above their heads before lowering the handgrip to their waist whilst squeezing the dynamometer as much as possible. 2 attempts were recorded for each hand, with the maximum attempt for both hands being recorded as the maximum grip strength. Grip strength asymmetry was also determined by subtracting the maximum grip strength in the right hand from that of the left hand.

2.3 Body Composition

Bioelectrical impedance analysis was measured to assess the body composition for each athlete. BIA data was recorded using the Bodystat 1500 MDD bio impedance analyser, which performs the analysis with a hand to foot electrode placement. The output of the analysis provided estimates of body fat percentage, fat weight, lean weight, dry lean weight, total body water and estimates of water percentage for each athlete.

2.4 Anthropometrics

Body limb segment lengths were recorded in order to assess the anthropometrical profile for each athlete. Specifically, Upper Arm, Torso, hand, Total Arm, Torso, thigh, tibia, and total leg measurements were recorded using the same methodology as Fry et al (2006). Segment to height ratios were also calculated for each athlete.

2.5 Slow stretch cycling utilization

Slow stretch cycling utilization (SSC) was used as a means to assess lower body explosive power. Slow SSC was assessed with the countermovement jump (CMJ) and the standing broad jump. The countermovement jump was assessed using the just jump mat and timing system. For the countermovement jump, the standard CMJ protocol was used in this study. Specifically, athletes were asked to perform a maximum jump after a single flexion of the knees and hips whilst keeping their hands on their hips and throughout the jump. The best of 2 attempts were recorded as the maximum jump height. Estimates of Peak power were then recorded using both the Sayers (Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999) and Duncan equation (Duncan, Hankey, & Nevill, 2013).

Additionally, another measure for SSC utilization was the standing broad jump. This measure has been included in the study in order to provide a simple alternative approach to measuring SSC utilization that can be applied in most field-based scenarios. The SBJ was recorded using a standing broad jump mat. To perform the standing broad jump, participants were asked to stand at the jump line on the mat and, with one full extension of the knees and hips, jump as far forward from the start line as possible. SBJ distance was calculated as the distance between the start line and the landing point of the closest foot to the start line. For each round of testing, the best of 2 jumps were recorded.

2.6 Squat mobility and trunk control

The overhead squat test was used to assess athlete squat mobility and trunk control. To complete this test, athletes were required to perform three repetitions of a full squat with an unloaded Olympic barbell. Participants were specifically asked to pause for 5 seconds at the bottom of the squat so that a photo of the squat could be taken.

For each athlete, the photo of the squat chosen was that which the athlete appeared to be in their most stable position. This was usually taken from the athletes second or third attempt, as any instability in the mechanics of the squat was often as a result of familiarisation with the test itself. Angles for the shin, thigh and torso relative to the torso were then recorded using a protractor that overlaid the photos. Angles at the knee (shin relative to thigh), hip (torso relative to thigh), and torso relative to shin, were also recorded to assess the squat mobility at all relative limp positions.

Trunk control was assessed using the overhead squat angle relative to horizonal and the torso angle relative to thigh.

3. Psychosocial profile

In order to monitor the psychosocial characteristics of each athlete, athletes were asked to complete an extended psychosocial inventory at the baseline of the study. This inventory was formed from a combination of existing inventories which was targeted towards the themes that were identified as discriminators of super elite performance in the great British medallists project (Hardy et al. 2017). These themes covered both athlete personality and attitudes towards training and competition and are summarised in table 1.

As shown in table 1, items used in the inventory were a combination of existing psychometric inventories, namely the 2 x 2 achievement goal questionnaire (Control et al., 2003), the important of others in the self-scale (Aron et al., 1992)., the ten-item personality inventory (TIPI; Gosling et al., 2003), the sport multidimensional perfectionism scale 2 (Sport MPS-2; Gotwals and Dunn, 2009), and the passion scale (Vallerand et al., 2003). Items were also generated as part of an early iteration of the athlete development formulation survey (Dunn et al., unpublished). These additional items were designed to target the themes as they were described by the in the great British medallist's study. These themes included mastery and outcome focus, commitment to training, total preparation for competition, and relative importance of sport.

The inventory consisted of 110 items. Athletes were asked to rate how much each item described themselves on a 7 point Likert scale, with 1 meaning 'Nothing like me' to 7 meaning 'Very much like me'. For any items in which the participant was unsure about, they were asked to circle as 4, which was labelled as 'I'm unsure'.

4. Sporting History and Weightlifting Specific Involvement

4.1 Sporting History

Athletes were asked to provide a list of sports they have been practicing or competing in starting from age 6 the their current age. This allowed for a detailed examination of the sporting history profile of each athlete. Additionally, this also allowed for the consideration of the exposure to sampling during early development, as well as the potential for any specialisation that may have occurred.

The number of sports participated at each chronological age year were included as attributes in the dataset, as well as the number of sports participated in for the age ranges of 6-12, and 13 to 15. These age windows were selected to reflect the sampling, and specialization years as indicated in the developmental model for sports participation (DMSP; Cote, 2002?).

Additionally, in order to profile the potential effects of transfer between specific sports and sport types, the years involved in each specific sport listed were also included in the dataset. Consequently, a total 27 unique sports were identified across the sample of participants. In addition, years of sports participation in team sports or individual sports, as well as for CGS sports (i.e. where performance is measurable be centimetres, grams or seconds). The count in years was not duplicated for any athlete that was involved in more than one sport per sport type (e.g. more than one team sport) during the same time period. As such, only a maximum of 7 years were countable for participating in a particular sport type between the ages of 6-12, and 3 years between 13 and 15.

4.2 Weightlifting Specific Involvement

Estimates of the time spent involved in Weightlifting was also included in the analysis. Specifically, athletes were asked to list the time spent involved in weightlifting (in months) for

each year they had been training and competing. They were also asked to list the time spent (in hours perk week) engaged in each of the following types of training: Weightlifting specific technical training, general strength and conditioning (including non-technical resistance training), flexibility and mobility training, They were also asked to list the number of competitions in which they competed and the time spent in the competition environment (in hours) for each year they were involved in weightlifting. These estimates allowed for the calculation of volume of time spent practicing each type of activity for each year and between testing sessions, which would allow for the comparison of potential differences in performance that were based on deliberate practice.

5. Practice activities in Weightlifting

Finally, athletes were profiled on the specific practice activities in which they engaged in weightlifting. These activities were recorded in the form of a one to one interview with each athlete at each testing session. The activities covered the following broad themes:

5.1 Deliberate practice versus deliberate play

Athletes were asked to identify the proportion of their weightlifting specific involvement that was goal directed, focused on the development of performance, was not inherently enjoyable (i.e. deliberate practice), versus the proportion of their weightlifting specific practice that was free from goal directed focus and was inherently enjoyable, termed deliberate play. Estimates of these proportions were used to calculate estimates of volumes of deliberate play and deliberate practice based on the total volume of weightlifting practice described in section 4.

5.2 Whole versus Part practice

For both the snatch and the clean and jerk, athletes were asked to list all of the practice activities in which they engaged in that was part of their regular technical training programme. For each exercise they completed, they were shown a diagram that shows the typical phases of movement execution for the snatch and clean and jerk (see figure 2) and were asked to highlight where each exercises started and ended in relation to each phase of execution. As expected, for both the snatch and clean and jerk, all phases of execution were covered in the start and end points for these lifts, and as such these exercises were classified as ‘whole practice’ exercises. For all other exercises listed, the start and end phase of execution were a subsection of the start and end phases as shown in figure 2, and as such were labelled as ‘part practice’ exercises.

Athletes were then asked to list the proportion of time spent performing these exercises relative to the whole amount of time spent practicing either the clean and jerk or the snatch. These proportions were estimated such that the proportions listed for each exercise would sum to 100 percent for both and snatch and the clean and jerk. This allowed for the estimation of the proportion of time spent practicing each lift as a whole as well as in parts.

Additionally, as the proportions were listed for each phases of execution, the volume of time spent practicing each phase of execution could be estimated by multiplying the sum of the proportion of time spent practicing each phase of execution for each lift by the total volume of weightlifting specific practice. An example of this breakdown can be seen in figure 3.

5.3 Constant versus varied practice

Athletes were also asked to provide an estimate of the proportion of time spent engaged in practice that was in a constant versus a varied practice conditions. Constant practice structure

referred to conditions in which practice was performed on a consistent practice environment. This could have included use of the same weightlifting platform, with the same equipment or with the same routine. In contrast, varied practice conditions referred to practice conditions in which practice was performed in different environments, on different surfaces or with an entirely different routine. These estimates were also multiplied by the total cumulative volume of practice at each time point in order to obtain an estimate of the total volume of varied and constant practice structure.

5.4 Internal versus external focus of attention

Athletes were also asked about the proportion of time they spent practicing with an internal and external focus of attention. Specifically, for the internal focus of attention, athletes were asked to think about the proportion time spent practicing whilst directing attention to the kinematics of their body during the technical phase of their training (i.e. training that was mainly focused on the acquisition and refinement of movement execution). For an external focus of attention, athletes were asked about the proportion of time they spent during attention towards something outside of the body.

5.5 Anxiety specificity

Athletes were also asked about the proportion of time during their technical phase of training that was spent practicing with the same level of emotion that is induced by competition. A typical example that was provided to the athletes would be a practice session or activity which would involve training with the same amount of load as they do in competition. Another example would be a training activity that would replicate the same consequences of their action to that of competition, such as practicing their opening weights or personal bests. In addition to proportion of time spent practicing, athletes were also asked to rate their typical experience of this practice on a scale of 1 to 10, with 10 being maximum difficulty. Estimates of the volume of time spent practicing with anxiety specificity was then calculated from the estimates of total volume of practice.

5.6 Context Specificity

Similarly, to the anxiety specificity, athletes were also asked about the proportion of their technical training that was organized to replicate the specific demands of competition. This would include practice that was structured with the same rest periods than that of competition (2 minutes between lifts) or with the use of the same loads. Athletes were also asked to rate these experiences on a scale of 1 to 10 (10 labelled at maximum). These estimates were also multiplied by the total volume of technical training in order to establish an estimate for context specificity.

5.7 Conveying of information

Athletes were also asked about the nature of the information that was conveyed to them from their coach. They were specifically asked if this information was ever conveyed was verbal, via a demonstration, or in video format. Athletes were then asked to split these types of information into proportions based on their prevalence. These proportions were subsequently used in the analysis.

5.8 Constraints versus prescriptive coaching

Lastly, athletes were asked about the nature of the coaching they experienced during their technical phase of training. Specifically, once appropriate definitions were introduced, participants were asked to provide an estimation in proportion of time spent with one of three practice conditions: constraints-based coaching, prescriptive coaching, and non-directional coaching. Constraints based coaching typically involves creating situations where learners are encouraged/forced to find solutions to weightlifting scenarios through exploration and discovery. In a little more detail, these scenarios are created by manipulating the task (such as the conditions imposed by the coach, manipulating the environment such as the height and/or space available on the lifting platform, the lifting surface, or lifting equipment, or manipulating the lifter, perhaps by limiting the lifters movement (e.g., with the use of ropes or elastic bands, or by manipulating clothing and footwear attire). Prescriptive coaching typically involves lots of demonstrations and verbal instructions about how to perform a lift in a technically correct fashion together with lots of feedback and guidance about how to adjust this technique on future attempts. Lastly, non-directional coaching refers to coaching in which no specific constraints or instruction is given, and as such the athlete is left to practice using their own exploratory mechanisms.

Table 26. Model coefficients for all linear models used to estimate normative data in pathway analyses

Model	Term	Estimate (standard error)	t-statistic	P value	p <.05
Maximum total (women)	Intercept	-168.94 (22.43)	-7.53	0	*
	Body weight (kg)	2.83 (1.18)	2.4	0.02	*
	Body weight (kg)^2	-0.03 (0.02)	-1.6	0.11	
	Body weight (kg)^3	0 (0)	1.64	0.1	
	Age	16.26 (1.31)	12.43	0	*
	Age^2	-0.41 (0.05)	-9.2	0	*
	Age^3	0 (0)	6.08	0	*
	Competitive experience	13.98 (0.89)	15.78	0	*
	Competitive experience^2	-1.5 (0.18)	-8.49	0	*
	Competitive experience^3	0.05 (0.01)	5.83	0	*
Maximum total (men)	Intercept	-256.98 (9.89)	-25.98	0	*
	Body weight (kg)	1.45 (0.35)	4.12	0	*
	Body weight (kg)^2	0.01 (0)	2.55	0.01	*
	Body weight (kg)^3	0 (0)	-5.03	0	*
	Age	26.99 (0.74)	36.47	0	*
	Age^2	-0.67 (0.02)	-32.12	0	*
	Age^3	0 (0)	26.45	0	*
	Competitive experience	10.97 (0.48)	22.63	0	*
	Competitive experience^2	-0.79 (0.05)	-15.78	0	*

Model	Term	Estimate (standard error)	t-statistic	P value	p <.05
	Competitive experience^3	0.01 (0)	12.95	0	*
Maximum snatch (women)	Intercept	-70.32 (11.74)	-5.99	0	*
	Body weight (kg)	1.12 (0.61)	1.83	0.07	
	Body weight (kg)^2	-0.01 (0.01)	-1.02	0.31	
	Body weight (kg)^3	0 (0)	0.97	0.33	
	Age	6.84 (0.68)	10.13	0	*
	Age^2	-0.18 (0.02)	-7.67	0	*
	Age^3	0 (0)	5.21	0	*
	Competitive experience	5.68 (0.46)	12.41	0	*
	Competitive experience^2	-0.54 (0.09)	-5.89	0	*
	Competitive experience^3	0.02 (0)	3.61	0	*
Maximum snatch (men)	Intercept	-110.05 (5.42)	-20.3	0	*
	Body weight (kg)	0.68 (0.19)	3.54	0	*
	Body weight (kg)^2	0 (0)	1.86	0.06	
	Body weight (kg)^3	0 (0)	-3.69	0	*
	Age	11.47 (0.4)	28.64	0	*
	Age^2	-0.29 (0.01)	-25.64	0	*
	Age^3	0 (0)	21.37	0	*
	Competitive experience	4.63 (0.26)	17.63	0	*
	Competitive experience^2	-0.31 (0.03)	-11.47	0	*
	Competitive experience^3	0.01 (0)	9.28	0	*
Maximum clean and jerk (women)	Intercept	-97.9 (15.2)	-6.44	0	*
	Body weight (kg)	2.25 (0.8)	2.83	0	*
	Body weight (kg)^2	-0.03 (0.01)	-2.22	0.03	*
	Body weight (kg)^3	0 (0)	2.26	0.02	*
	Age	8.19 (0.88)	9.33	0	*
	Age^2	-0.21 (0.03)	-6.88	0	*
	Age^3	0 (0)	4.46	0	*
	Competitive experience	6.12 (0.59)	10.31	0	*
	Competitive experience^2	-0.54 (0.12)	-4.51	0	*
	Competitive experience^3	0.02 (0.01)	2.82	0	*
Maximum clean and jerk (men)	Intercept	-139.05 (6.89)	-20.18	0	*
	Body weight (kg)	1.33 (0.24)	5.42	0	*
	Body weight (kg)^2	0 (0)	-0.14	0.89	
	Body weight (kg)^3	0 (0)	-2.25	0.02	*
	Age	13.23 (0.51)	25.98	0	*
	Age^2	-0.33 (0.01)	-22.85	0	*
	Age^3	0 (0)	18.67	0	*

Model	Term	Estimate (standard error)	t-statistic	P value	p <.05
	Competitive experience	5.65 (0.34)	16.82	0	*
	Competitive experience^2	-0.38 (0.03)	-11	0	*
	Competitive experience^3	0.01 (0)	8.78	0	*
Snatch first attempt (women)	Intercept	-73.96 (9.36)	-7.9	0	*
	Body weight (kg)	1.05 (0.5)	2.11	0.03	*
	Body weight (kg)2	-0.01 (0.01)	-1.29	0.2	
	Body weight (kg)^3	0 (0)	1.25	0.21	
	Age	7.15 (0.56)	12.81	0	*
	Age^2	-0.18 (0.02)	-9.42	0	*
	Age^3	0 (0)	6.17	0	*
	Competitive experience	6.49 (0.4)	16.34	0	*
	Competitive experience^2	-0.66 (0.08)	-8.05	0	*
	Competitive experience^3	0.02 (0)	5.07	0	*
Snatch first attempt (men)	Intercept	-116.54 (4.14)	-28.17	0	*
	Body weight (kg)	0.42 (0.15)	2.86	0	*
	Body weight (kg)^2	0.01 (0)	4.02	0	*
	Body weight (kg)^3	0 (0)	-6.5	0	*
	Age	12.37 (0.31)	40.3	0	*
	Age^2	-0.31 (0.01)	-35.74	0	*
	Age^3	0 (0)	29.55	0	*
	Competitive experience	5.25 (0.21)	25.22	0	*
	Competitive experience^2	-0.39 (0.02)	-18.38	0	*
	Competitive experience^3	0.01 (0)	15.46	0	*
Clean & jerk first attempt (women)	Intercept	-91.95 (11.36)	-8.09	0	*
	Body weight (kg)	1.38 (0.6)	2.29	0.02	*
	Body weight (kg)^2	-0.02 (0.01)	-1.69	0.09	
	Body weight (kg)^3	0 (0)	1.94	0.05	*
	Age	9.34 (0.69)	13.59	0	*
	Age^2	-0.24 (0.02)	-10.17	0	*
	Age^3	0 (0)	6.87	0	*
	Competitive experience	7.58 (0.48)	15.78	0	*
	Competitive experience^2	-0.76 (0.1)	-7.68	0	*
	Competitive experience^3	0.02 (0.01)	4.95	0	*
Clean & jerk first attempt (men)	Intercept	-142.62 (4.9)	-29.12	0	*
	Body weight (kg)	0.69 (0.17)	3.95	0	*
	Body weight (kg)^2	0.01 (0)	3.2	0	*
	Body weight (kg)^3	0 (0)	-5.92	0	*
	Age	14.95 (0.36)	41.03	0	*

Model	Term	Estimate (standard error)	t-statistic	P value	p <.05
	Age^2	-0.37 (0.01)	-36.24	0	*
	Age^3	0 (0)	29.9	0	*
	Competitive experience	6 (0.25)	24.35	0	*
	Competitive experience^2	-0.45 (0.03)	-17.62	0	*
	Competitive experience^3	0.01 (0)	14.8	0	*
Snatch second attempt load increase (women)	Intercept	-2.06 (0.94)	-2.19	0.03	*
	Body weight (kg)	0.11 (0.05)	2.08	0.04	*
	Body weight (kg)^2	0 (0)	-1.78	0.08	
	Body weight (kg)^3	0 (0)	1.82	0.07	
	Age	0.24 (0.06)	4.24	0	*
	Age^2	-0.01 (0)	-3.6	0	*
	Age^3	0 (0)	2.96	0	*
Snatch second attempt load increase (men)	Intercept	-^{3}.67 (0.46)	-8.06	0	*
	Body weight (kg)	0.12 (0.02)	6.67	0	*
	Body weight (kg)^2	0 (0)	-3.96	0	*
	Body weight (kg)^3	0 (0)	2.45	0.01	*
	Age	0.28 (0.03)	10.04	0	*
	Age^2	-0.01 (0)	-8.05	0	*
	Age^3	0 (0)	6.25	0	*
Clean & jerk second attempt load increase (women)	Intercept	-1.27 (1.22)	-1.04	0.3	
	Body weight (kg)	0.09 (0.07)	1.31	0.19	
	Body weight (kg)^2	0 (0)	-0.92	0.36	
	Body weight (kg)^3	0 (0)	0.88	0.38	
	Age	0.2 (0.07)	2.62	0.01	*
	Age^2	0 (0)	-1.86	0.06	
	Age^3	0 (0)	1.24	0.22	
Clean & jerk third attempt load increase (women)	Intercept	0.25 (1.2)	0.21	0.83	
	Body weight (kg)	0 (0.07)	-0.04	0.97	
	Body weight (kg)^2	0 (0)	0.18	0.86	
	Body weight (kg)^3	0 (0)	-0.14	0.89	
	Age	0.19 (0.08)	2.38	0.02	*
	Age^2	0 (0)	-1.62	0.11	
	Age^3	0 (0)	1.11	0.27	
Snatch third attempt load increase (women)	Intercept	-1.3 (1)	-1.31	0.19	
	Body weight (kg)	0.06 (0.06)	1.07	0.28	
	Body weight (kg)^2	0 (0)	-0.71	0.48	
	Body weight (kg)^3	0 (0)	0.65	0.52	

Model	Term	Estimate (standard error)	t-statistic	P value	p <.05
	Age	0.2 (0.06)	3.11	0	*
	Age^2	-0.01 (0)	-2.65	0.01	*
	Age^3	0 (0)	2.23	0.03	*
Snatch third attempt load increase (men)	Intercept	-2.31 (0.57)	-4.07	0	*
	Body weight (kg)	0.05 (0.02)	2.2	0.03	*
	Body weight (kg)^2	0 (0)	-0.47	0.64	
	Body weight (kg)^3	0 (0)	-0.26	0.8	
	Age	0.29 (0.04)	7.64	0	*
	Age^2	-0.01 (0)	-6.37	0	*
	Age^3	0 (0)	5.01	0	*
Clean & jerk second attempt load increase (women)	Intercept	-4.15 (0.56)	-7.36	0	*
	Body weight (kg)	0.08 (0.02)	3.9	0	*
	Body weight (kg)^2	0 (0)	-1.52	0.13	
	Body weight (kg)^3	0 (0)	0.28	0.78	
	Age	0.46 (0.04)	10.65	0	*
	Age^2	-0.01 (0)	-8.79	0	*
	Age^3	0 (0)	6.99	0	*
Clean & jerk third attempt load increase (men)	Intercept	-3.04 (0.75)	-4.07	0	*
	Body weight (kg)	0.08 (0.03)	2.43	0.02	*
	Body weight (kg)^2	0 (0)	-1.28	0.2	
	Body weight (kg)^3	0 (0)	0.99	0.32	
	Age	0.33 (0.04)	8.05	0	*
	Age^2	-0.01 (0)	-6.76	0	*
	Age^3	0 (0)	5.48	0	*

Table 27. Logical attributes for women at u15

Attribute	Pathway	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Competitive performances					
Total above norm at u15	Senior	3/41 (7.3%)	3/11 (27.3%)	3.17 (0.86 – 23.76)	-
	U17	33/109 (30.3%)	11/12 (91.7%)	12.29 (3.04 -100.7)	High
Weight selection in competition					
First attempt for the snatch above norm at u15	Senior	3/41 (7.3%)	2/11 (18.2%)	1.9 (0.49 – 17.02)	-
	U17	30/109 (27.5%)	11/12 (91.7%)	14.02 (3.47 – 115.2)	High
	Senior	2/41 (4.9%)	1/11 (9.1%)	1.18 (0.27 - 19.1)	-

Load increase for the snatch second attempt at least 0.5 kg above norm at u15	U17	15/109 (13.8%)	5/12 (41.7%)	3.67 (1.31 - 15.21)	Moderate
Load increase for the snatch third attempt above norm at u15	Senior	7/41 (17.1%)	2/11 (18.2%)	0.85 (0.24 - 6)	-
	U17	30/109 (27.5%)	5/12 (41.7%)	1.59 (0.59 – 6.2)	-
First attempt for the clean & jerk at least 1kg above norm at u15	Senior	2/41 (4.9%)	3/11 (27.3%)	4.33 (1.09 - 38.74)	Moderate
	U17	29/109 (26.6%)	11/12 (91.7%)	14.67 (3.62 - 120.8)	High
Load increase for the clean & jerk second attempt above norm at u15	Senior	8/41 (19.5%)	1/11 (9.1%)	0.33 (0.09 - 3.65)	-
	U17	38/109 (34.9%)	7/12 (58.3%)	2.12 (0.79 - 8.14)	-
Load increase for the clean & jerk third attempt above norm at u15	Senior	3/41 (7.3%)	2/11 (18.2%)	1.9 (0.49 - 17.02)	-
	U17	20/109 (18.3%)	6/12 (50%)	3.63 (1.33 - 14.33)	Moderate
Competitive History					
1.7 or more years of competitive experience at u15	Senior	5/41 (12.2%)	2/11 (18.2%)	1.2 (0.33 - 9.15)	-
	U17	17/109 (15.6%)	7/12 (58.3%)	5.96 (2.14 - 24.25)	High
Competed in at least 5 events at u15	Senior	2/41 (4.9%)	2/11 (18.2%)	2.6 (0.63 - 27.54)	-
	U17	7/109 (6.4%)	5/12 (41.7%)	7.97 (2.66 - 37.77)	High
Competed in a British junior event at least 1 time at u15	Senior	8/41 (19.5%)	2/11 (18.2%)	0.73 (0.21 - 5.05)	-
	U17	24/109 (22%)	7/12 (58.3%)	3.97 (1.45 - 15.62)	Moderate
Competed in an International developmental junior event at least 1 time at u15	Senior	0/41 (0%)	2/11 (18.2%)	8.2 (0.97 - 493.22)	Moderate
	U17	18/109 (16.5%)	4/12 (33.3%)	2.13 (0.75 - 9.11)	-
Competed in a continental youth event at least 1 time at u15	Senior	0/41 (0%)	1/11 (9.1%)	3.73 (0.45 - 312.43)	-
	U17	0/109 (0%)	2/12 (16.7%)	19.82 (2.35 - 1159.41)	Moderate

Key: FPR = False positive rate, TPR = true positive rate, CI = confidence interval. Note: Importance level was only determined for the odds ratios in which the confidence interval range did not include 1.

Table 28. Logical attributes for women at u17

Attribute	Pathway	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Competitive performances					
Total at least 7.5kg above norm at u17	Senior	1/41 (2.4%)	4/11 (36.4%)	10 (2.18 – 120.35)	Moderate
	U20	28/90 (31.1%)	9/9 (100%)	19.24 (2.34 – 740.86)	High
Weight selection in competition					
First attempt for the snatch at least 3.5kg above norm at u17	Senior	5/41 (12.2%)	4/11 (36.4%)	3 (0.91 - 17.37)	-
	U20	29/90 (32.2%)	9/9 (100%)	18.3 (2.23 - 703.86)	High
Load increase for the snatch second attempt by at least 0.5 kg above norm at u17	Senior	5/41 (12.2%)	4/11 (36.4%)	3 (0.91 - 17.37)	-
	U20	18/90 (20%)	5/9 (55.6%)	3.79 (1.25 - 18.41)	Moderate

Load increase for the snatch third attempt above norm at u17	Senior	5/41 (12.2%)	2/11 (18.2%)	1.2 (0.33 - 9.15)	-
	U20	30/90 (33.3%)	5/9 (55.6%)	1.94 (0.65 - 9.07)	-
First attempt for the clean & jerk at least 4.5kg above norm at u17	Senior	1/41 (2.4%)	4/11 (36.4%)	10 (2.18 – 120.35)	Moderate
	U20	16/90 (17.8%)	8/9 (88.9%)	25.12 (3.06 – 974.44)	High
Load increase for the clean & jerk second attempt above norm at u17	Senior	10/41 (24.3%)	3/11 (27.3%)	0.94 (0.3 – 5.15)	-
	U20	33/90 (36.7%)	7/9 (77.8%)	3.91 (1.16 – 22.93)	High
Load increase for the clean & jerk third attempt above norm at u17	Senior	3/41 (7.3%)	1/11 (9.1%)	0.86 (0.21 - 11.97)	-
	U20	16/90 (17.8%)	2/9 (22.2%)	1.09 (0.33 - 6.93)	-
Competitive History					
3.8 or more years of competitive experience at u17	Senior	2/41 (4.9%)	2/11 (18.2%)	2.6 (0.63 - 27.54)	-
	U20	6/90 (6.7%)	3/9 (33.3%)	5.14 (1.52 - 32.16)	Moderate
Competed in at least 11 events at u17	Senior	0/41 (0%)	2/11 (18.2%)	8.2 (0.97 – 493.22)	High
	U20	2/90 (2.2%)	3/9 (33.3%)	12.57 (3.13 – 116.2)	High
Competed in a British senior event at least 1 time at u17	Senior	7/41 (17.1%)	3/11 (27.3%)	1.42 (0.43 - 8.27)	-
	U20	14/90 (15.6%)	7/9 (77.8%)	11.82 (3.4 - 73.65)	High
Competed in a continental youth event at least 1 time at u17	Senior	0/41 (0%)	3/11 (27.3%)	13.67 (1.61 - 724.31)	Moderate
	U20	1/90 (1.1%)	3/9 (33.3%)	19.07 (4.05 - 255.07)	High

Table 29 . Logical attributes for women at u20

Attribute	Pathway	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Competitive performances					
Total at least 6.5kg above norm at u20	Senior	2/41 (4.9%)	7/11 (63.4%)	18.2 (4.66 – 148.83)	High
	U23	17/54 (31.5%)	8/9 (88.9%)	8.22 (1.96 – 75.4)	High
Weight selection in competition					
First attempt for the snatch at least 4kg above norm at u20	Senior	2/41 (4.9%)	7/11 (63.6%)	18.2 (4.66 – 148.8)	High
	U23	15/54 (27.8%)	8/9 (88.9%)	9.75 (2.31 – 90.25)	High
Load increase for the snatch second attempt above norm at u20	Senior	6/41 (14.6%)	3/11 (27.3%)	1.67 (0.5 - 10.07)	-
	U23	9/54 (16.7%)	3/9 (33.3%)	1.93 (0.59 - 11.28)	-
Load increase for the snatch third attempt above norm at u20	Senior	7/41 (17.1%)	1/11 (9.1%)	0.39 (0.1 - 4.32)	-
	U23	13/54 (24.1%)	1/9 (11.1%)	0.33 (0.09 - 3.42)	-
First attempt for the clean & jerk at least 3.5kg above norm at u20	Senior	4/41 (9.8%)	7/11 (63.6%)	10.4 (3.03 – 63.74)	High
	U23	17/54 (31.5%)	8/9 (88.9%)	8.22 (1.96 – 75.41)	High
Load increase for the clean & jerk second attempt above norm at u20	Senior	9/41 (22%)	6/11 (54.5%)	3.2 (1.05 - 15.54)	
	U23	11/54 (20.4%)	5/9 (55.6%)	3.58 (1.13 - 18.84)	Moderate
Load increase for the clean & jerk third attempt above norm at u20	Senior	4/41 (9.8%)	4/11 (36.4%)	3.7 (1.09 - 22.95)	-
	U23	6/54 (11.1%)	1/9 (11.1%)	0.76 (0.19 - 8.97)	-
Competitive History					
4.6 or more years of competitive experience at u20	Senior	5/41 (12.2%)	4/11 (36.4%)	3 (0.91 - 17.37)	-
	U23	6/54 (11.1%)	4/9 (44.4%)	4.57 (1.37 - 27.11)	Moderate

Competed in at least 12 events at u20	Senior	2/41 (4.9%)	3/11 (27.3%)	4.33 (1.09 – 38.74)	Moderate
	U23	3/54 (5.6%)	3/9 (33.3%)	5.46 (1.46 - 43)	Moderate
Competed in a British senior event at least 2 times at u20	Senior	4/41 (9.8%)	5/11 (45.5%)	5.29 (1.58 - 31.55)	Moderate
	U23	7/54 (13%)	3/9 (33.3%)	2.52 (0.75 - 15.45)	-
Won a gold medal at a British senior event at u20	Senior	6/41 (14.6%)	5/11 (45.5%)	3.57 (1.13 - 18.93)	Moderate
	U23	11/54 (20.4%)	7/9 (77.8%)	8.36 (2.36 - 54.65)	High
Competed in a world senior event at least 1 time at u20	Senior	0/41 (0%)	4/11 (36.4%)	20.5 (2.42 - 1024)	High
	U23	1/54 (1.9%)	3/9 (33.3%)	11.36 (2.4 - 153.54)	Moderate

Table 30. Logical attributes for women at u23

Attribute	Pathway	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Competitive performances					
Total at least 11kg above norm at u23	top-down	5/41 (12.2%)	9/11 (81.2%)	18 (4.81 – 132.19)	High
	bottom-up	14/48 (29.2%)	15/16 (93.8%)	17 (4.13 – 146.48)	High
Weight selection in competition					
First attempt for the snatch at least 4.5kg above norm at u23	top-down	5/41 (12.2%)	7/11 (63.6%)	8.54 (2.54 – 48.25)	High
	bottom-up	14/48 (29.2%)	14/16 (87.5%)	10.58 (3.15 – 60.36)	High
Load increase for the snatch second attempt above norm at u23	top-down	9/41 (22%)	5/11 (45.5%)	2.29 (0.75 - 11.12)	-
	bottom-up	16/48 (33.3%)	7/16 (43.8%)	1.32 (0.5 - 4.79)	-
Load increase for the snatch third attempt above norm at u23	top-down	6/41 (14.6%)	5/11 (36.4%)	3.57 (1.13 – 18.93)	Moderate
	bottom-up	15/48 (31.2%)	4/16 (25%)	0.63 (0.23 - 2.67)	-
First attempt for the clean & jerk at least 6.5kg above norm at u23	top-down	6/41 (14.6%)	8/11 (72.3%)	10 (2.96 – 59.42)	High
	bottom-up	16/48 (33.3%)	15/16 (93.8%)	14.12 (3.44 – 120.4)	High
Load increase for the clean & jerk second attempt above norm at u23	top-down	11/41 (26.8%)	7/11 (63.6%)	3.5 (1.14 - 17.07)	Moderate
	bottom-up	20/48 (41.7%)	8/16 (50%)	1.19 (0.46 - 4.21)	-
Load increase for the clean & jerk third attempt above norm at u23	top-down	5/41 (12.2%)	4/11 (36.4%)	3 (0.91 - 17.37)	-
	bottom-up	9/48 (18.8%)	2/16 (12.5%)	0.52 (0.16 - 3.27)	-
Competitive History					
8.2 or more years of competitive experience at u23	top-down	1/41 (2.4%)	3/11 (27.3%)	6.67 (1.43 - 86.42)	Moderate
	bottom-up	0/48 (0%)	5/16 (31.2%)	20 (2.39 - 900.26)	High
Competed in at least 11 events at u23	top-down	1/41 (2.4%)	4/11 (36.4%)	10 (2.18 - 120.35)	Moderate
	bottom-up	1/48 (2.1%)	3/16 (18.8%)	5.04 (1.1 - 61.03)	Moderate
Competed in a British senior event at least 3 time at u23	top-down	4/41 (9.8%)	7/11 (63.6%)	10.36 (3.03 - 63.74)	High
	bottom-up	2/48 (4.2%)	5/16 (31.2%)	6.39 (1.75 - 45.33)	Moderate
Won a gold medal at a British senior event at u23	top-down	2/41 (4.9%)	6/11 (54.5%)	13 (3.38 - 103.22)	High
	bottom-up	5/48 (10.4%)	10/16 (62.5%)	10.24 (3.41 - 47.9)	High
Competed in a world senior event at least 1 time at u23	top-down	0/41 (0%)	3/11 (27.3%)	13.67 (1.61 - 724.3)	Moderate
	bottom-up	0/48 (0%)	4/16 (25%)	14.77 (1.76 - 692.4)	Moderate

Table 31. Logical attributes for men at u13

Attribute	Pathway	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Competitive performances					
Total at least 3kg above norm at u13	Senior	3/40 (7.5%)	5/12 (41.7%)	5.78 (1.66 - 37.12)	Moderate
	U15	74/238 (31.1%)	18/26 (69.2%)	4.37 (2.04 – 11.32)	Moderate
Weight selection in competition					
First attempt for the snatch above norm at u13	Senior	2/40 (5%)	4/12 (33.3%)	5.63 (1.47 - 45.31)	Moderate
	U15	84/238 (35.2%)	21/26 (80.8%)	6.34 (2.7 – 18.9)	Moderate
Load increase for the snatch second attempt above norm at u13	Senior	1/40 (2.5%)	3/12 (25%)	5.85 (1.26 - 74.59)	Moderate
	U15	62/238 (26.1%)	10/26 (38.5%)	1.64 (0.79 - 4.1)	-
Load increase for the snatch third attempt above norm at u13	Senior	1/40 (2.5%)	3/12 (25%)	5.85 (1.26 - 74.59)	Moderate
	U15	61/238 (25.6%)	8/26 (30.8%)	1.2 (0.56 - 3.14)	-
First attempt for the clean & jerk at least 1.5kg above norm at u13	Senior	3/40 (7.5%)	5/12 (41.7%)	5.78 (1.66 - 37.12)	Moderate
	U15	78/238 (32.7%)	18/26 (69.2%)	4.05 (1.89 – 10.47)	Moderate
Load increase for the clean & jerk second attempt above norm at u13	Senior	1/40 (2.5%)	3/12 (25%)	5.85 (1.26 - 74.59)	Moderate
	U15	59/238 (24.8%)	8/26 (30.8%)	1.26 (0.58 - 3.29)	-
Load increase for the clean & jerk third attempt above norm at u13	Senior	1/40 (2.5%)	3/12 (25%)	5.85 (1.26 - 74.59)	Moderate
	U15	63/238 (26.5%)	11/26 (42.3%)	1.88 (0.91 - 4.63)	-
Competitive History					
0.11 or more years of competitive experience at u13	Senior	3/40 (7.5%)	5/12 (41.7%)	5.78 (1.66 - 37.12)	Moderate
	U15	84/238 (35.3%)	16/26 (61.5%)	2.64 (1.27 - 6.51)	Moderate
Competed in at least 2 events at u13	Senior	2/40 (5%)	4/12 (33.3%)	5.63 (1.47 - 45.31)	Moderate
	U15	30/238 (12.6%)	10/26 (38.5%)	3.95 (1.84 - 10.3)	Moderate
Competed in a British youth event at least 1 time at u13	Senior	3/40 (7.5%)	5/12 (41.7%)	5.78 (1.66 - 37.12)	Moderate
	U15	133/238 (55.9%)	17/26 (65.4%)	1.33 (0.63 - 3.34)	-
Finished 4th or higher in a British at u13 youth event	Senior	2/40 (5%)	5/12 (41.7%)	7.92 (2.09 - 61.04)	High
	U15	87/238 (36.6%)	15/26 (57.7%)	2.14 (1.04 - 5.23)	Moderate

Table 32. Logical attributes for men at u15

Attribute	Pathway	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Competitive performances					
Total at least 3.5kg above norm at u15	Senior	2/40 (5%)	6/12 (50%)	10.86 (2.87 - 82.53)	High
	U17	93/309 (30.1%)	33/40 (82.5%)	9.48 (4.52 – 23.67)	High
Weight selection in competition					
First attempt for the snatch at least 1kg above norm at u15	Senior	3/40 (7.5%)	6/12 (50%)	7.93 (2.29 - 50.15)	High
	U17	101/309 (32.7%)	34/40 (85%)	9.9 (4.56 – 26.05)	High
	Senior	3/40 (7.5%)	2/12 (16.7%)	1.68 (0.44 - 14.85)	-

Load increase for the snatch second attempt above norm at u15	U17	126/309 (40.8%)	22/40 (55%)	1.67 (0.92 - 3.4)	-
Load increase for the snatch third attempt above norm at u15	Senior	2/40 (5%)	2/12 (16.7%)	2.3 (0.56 - 24.06)	-
	U17	93/309 (30.1%)	16/40 (40%)	1.47 (0.8 - 3.05)	-
First attempt for the clean & jerk at least 1kg above norm at u15	Senior	4/40 (10%)	6/12 (50%)	6.17 (1.88 - 35.04)	High
	U17	100/309 (32.3%)	36/40 (90%)	14.9 (6.2 – 46.32)	High
Load increase for the clean & jerk second attempt above norm at u15	Senior	3/40 (7.5%)	6/12 (50%)	7.93 (2.29 - 50.15)	High
	U17	132/309 (42.7%)	20/40 (50%)	1.27 (0.7 - 2.57)	-
Load increase for the clean & jerk third attempt above norm at u15	Senior	4/40 (10%)	1/12 (8.3%)	0.6 (0.15 - 7.53)	-
	U17	89/309 (28.8%)	17/40 (42.5%)	1.73 (0.94 - 3.57)	-
Competitive History					
Competed in weightlifting for 1.8 or more years of competitive experience at u15	Senior	3/40 (7.5%)	6/12 (50%)	7.93 (2.29 - 50.15)	High
	U17	77/309 (24.9%)	23/40 (57.5%)	3.8 (2.06 - 7.87)	Moderate
Competed in at least 5 events at u15	Senior	4/40 (10%)	5/12 (41.7%)	4.5 (1.36 – 26.95)	Moderate
	U17	38/309 (12.3%)	21/40 (52.5%)	7.3 (3.86 – 15.65)	High
Competed in a British youth event at least 2 times at u15	Senior	8/40 (20%)	7/12 (58.3%)	4.15 (1.37 – 19.8)	High
	U17	201/309 (65%)	35/40 (87.5%)	3.12 (1.37 – 8.79)	High
Finished 4th place or higher at a British youth event at u15	Senior	6/40 (15%)	7/12 (58.3%)	5.67 (1.82 – 28.86)	High
	U17	139/309 (45%)	32/40 (80%)	4.32 (2.13 – 10.27)	High
Competed in a British junior event at least 1 time at u15	Senior	4/40 (10%)	4/12 (33.3%)	3.2 (0.95 - 19.34)	-
	U17	35/309 (11.3%)	25/40 (62.5%)	11.89 (6.18 - 26.18)	High
Competed in an International developmental junior event at least 1 at u15 time	Senior	2/40 (5%)	4/12 (33.3%)	5.63 (1.47 - 45.31)	Moderate
	U17	61/309 (19.7%)	12/40 (30%)	1.66 (0.86 - 3.65)	-

Table 33. Logical attributes for men at u17

	Pathway	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Competitive performances					
Total at least 7kg above norm at u17	Senior	5/40 (12.5%)	5/12 (41.7%)	3.65 (1.14 – 19.59)	Moderate
	U20	102/271 (37.8%)	23/25 (92%)	12.5 (4.1 – 58.24)	High
Weight selection in competition					
First attempt for the snatch at least 8kg above norm at u17	Senior	1/40 (2.5%)	3/12 (25%)	5.85 (1.26 – 74.59)	Moderate
	U20	81/271 (29.8%)	22/25 (88%)	12.74 (4.73 – 47.73)	High
Load increase for the snatch second attempt above norm at u17	Senior	8/40 (20%)	5/12 (41.7%)	2.22 (0.74 - 10.65)	-
	U20	122/271 (45%)	21/25 (84%)	5.09 (2.05 - 16.56)	Moderate
Load increase for the snatch third attempt above norm at u17	Senior	2/40 (5%)	2/12 (16.7%)	2.3 (0.56 - 24.06)	-
	U20	53/271 (19.6%)	13/25 (52%)	4.04 (1.93 - 10.07)	Moderate
First attempt for the clean & jerk at least 3kg above norm at u17	Senior	5/40 (12.5%)	5/12 (41.7%)	3.65 (1.14 – 19.59)	Moderate
	U20	78/271 (28.8%)	23/25 (92%)	18.73 (6.13 - 87.61)	High
	Senior	10/40 (25%)	4/12 (33.3%)	1.21 (0.4 - 5.88)	-

Load increase for the clean & jerk second attempt above norm at u17	U20	103/271 (38%)	13/25 (52%)	1.62 (0.78 - 3.94)	-
Load increase for the clean & jerk third attempt above norm at u17	Senior	6/40 (15%)	1/12 (8.3%)	0.4 (0.1 - 4.61)	-
	U20	91/271 (33.6%)	10/25 (40%)	1.22 (0.59 – 3.04)	-
Competitive History					
3.7 or more years of competitive experience at u17	Senior	5/40 (12.5%)	5/12 (41.7%)	3.65 (1.14 - 19.59)	Moderate
	U20	20/271 (11.1%)	15/25 (60%)	10.56 (4.88 – 27.76)	High
Competed in at least 6 events at u17	Senior	7/40 (17.5%)	6/12 (50%)	3.54 (1.16 – 17.14)	Moderate
	U20	15/271 (5.5%)	10/25 (40%)	10 (4.4 – 28.59)	Moderate
Competed in a British junior event at least 1 time at u17	Senior	12/40 (30%)	7/12 (58.3%)	2.51 (0.86 - 11.24)	-
	U20	85/271 (31.5%)	21/25 (84%)	9.03 (3.64 – 20.56)	High
Won a silver medal or higher at a British junior event at u17	Senior	6/40 (15%)	6/12 (50%)	4.16 (1.35 - 20.94)	Moderate
	U20	49/271 (18.1%)	19/25 (76%)	12 (5.25 – 34.35)	High
Competed in a world youth event at least 1 time at u17	Senior	0/40 (0%)	1/12 (8.3%)	3.33 (0.4 - 277.13)	-
	U20	2/271 (0.7%)	2/25 (8%)	7.47 (1.89 - 69.59)	Moderate

Table 34. Logical attributes for men at u20

Attribute	Pathway	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Competitive performances					
Average total more than 27.5kg above norm at u20	Senior	5/40 (12.5%)	6/12 (50%)	5 (1.58 - 26.44)	High
	U23	52/176 (29.5%)	26/30 (86.7%)	12.2 (4.89 – 39.91)	High
Weight selection in competition					
First attempt for the snatch at least 8kg above norm at u20	Senior	9/40 (22.5%)	8/12 (66.7%)	4.96 (1.62 - 24.24)	High
	U23	56/176 (31.2%)	26/30 (86.7%)	10.95 (4.4 – 35.82)	High
Load increase for the snatch second attempt above norm at u20	Senior	3/40 (7.5%)	5/12 (41.7%)	5.78 (1.66 - 37.12)	Moderate
	U23	76/176 (43.2%)	18/30 (60%)	1.8 (0.89 - 4.23)	-
Load increase for the snatch third attempt above norm at u20	Senior	3/40 (7.5%)	4/12 (33.3%)	4.11 (1.16 - 27.62)	Moderate
	U23	51/176 (29%)	10/30 (33.3%)	1.14 (0.55 - 2.81)	-
First attempt for the clean & jerk at least 9.5kg above norm at u20	Senior	15/40 (37.5%)	12/12 (100%)	18.75 (2.27 - 744.8)	High
	U23	58/176 (33%)	27/30 (90%)	13.5 (5.01 – 50.55)	High
Load increase for the clean & jerk second attempt above norm at u20	Senior	10/40 (25%)	7/12 (58.3%)	3.18 (1.07 - 14.6)	Moderate
	U23	44/176 (25%)	15/30 (50%)	2.75 (1.36 - 6.51)	Moderate
Load increase for the clean & jerk third attempt above norm at u20	Senior	5/40 (12.5%)	4/12 (33.3%)	2.59 (0.8 - 14.62)	-
	U23	43/176 (24.4%)	12/30 (40%)	1.91 (0.94 - 4.59)	-
Competitive History					
6.8 or more years of competitive experience at u20	Senior	5/40 (12.5%)	5/12 (41.7%)	3.65 (1.14 - 19.59)	Moderate
	U23	10/176 (5.7%)	8/30 (26.7%)	5.25 (2.19 - 16.38)	Moderate
Competed in at least 10 events at u20	Senior	2/40 (5%)	5/12 (41.7%)	7.92 (2.09 - 61.04)	Moderate
	U23	4/176 (2.3%)	9/30 (30%)	14.07 (5.06 - 56.68)	Moderate
Competed in a British junior event at least 2 times at u20	Senior	10/40 (25%)	8/12 (66.7%)	4.36 (1.44 – 20.97)	High
	U23	30/176 (17%)	19/30 (63.3%)	7.46 (3.56 – 18.61)	High

Won a silver medal or higher in a British junior event at u20	Senior	6/40 (15%)	6/12 (50%)	4.16 (1.35 - 20.94)	Moderate
	U23	45/176 (25.6%)	17/30 (56.7%)	3.46 (1.71 – 8.22)	Moderate
Competed in a British senior event at least 1 time at u20	Senior	10/40 (25%)	9/12 (75%)	6.14 (1.92 - 32.36)	High
	U23	23/176 (13.1%)	24/30 (80%)	21.86 (9.36 - 64.79)	High
Finished 4th or higher in a British senior event at u20	Senior	9/40 (22.5%)	9/12 (75%)	6.97 (2.17 - 37.39)	High
	U23	22/176 (12.5%)	24/30 (80%)	22.96 (9.8 - 68.36)	High
Competed in a world junior event at least 1 time at u20	Senior	0/40 (0%)	4/12 (33.3%)	17.78 (2.11 - 873.3)	High
	U23	5/176 (2.8%)	6/30 (20%)	6.84 (2.46 - 27.79)	Moderate

Table 35. Logical attributes for men at u23

Attribute	Pathway	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Competitive performances					
Average total more than 23.5kg above norm at u23	top-down	15/40 (37.5%)	9/12 (75%)	3.52 (1.13 - 17.72)	High
	bottom-up	56/147 (38.1%)	25/30 (83.3%)	6.65 (2.82 – 20)	High
Weight selection in competition					
First attempt for the snatch at least 11kg units above norm at u23	top-down	12/40 (30%)	9/12 (75%)	4.85 (1.53 - 24.95)	High
	bottom-up	43/147 (29.2%)	20/30 (66.7%)	4.3 (2.06 – 10.7)	High
Load increase for the snatch second attempt above norm at u23	top-down	10/40 (25%)	4/12 (33.3%)	1.21 (0.4 - 5.88)	-
	bottom-up	59/147 (40.1%)	9/30 (30%)	0.6 (0.29 - 1.51)	-
Load increase for the snatch third attempt above norm at u23	top-down	9/40 (22.5%)	4/12 (33.3%)	1.38 (0.45 - 6.8)	-
	bottom-up	42/147 (28.6%)	8/30 (26.7%)	0.85 (0.39 - 2.23)	-
First attempt for the clean & jerk at least 12kg above norm at u23	top-down	17/40 (42.5%)	10/12 (83.3%)	4.26 (1.24 – 25.6)	High
	bottom-up	42/147 (28.6%)	21/30 (70%)	5.13 (2.42 – 13.1)	High
Load increase for the clean & jerk second attempt above norm at u23	top-down	15/40 (37.5%)	5/12 (41.7%)	0.98 (0.34 - 4.29)	-
	bottom-up	32/147 (21.7%)	11/30 (36.7%)	1.92 (0.92 – 4.79)	-
Load increase for the clean & jerk third attempt above norm at u23	top-down	9/40 (22.5%)	3/12 (25%)	0.93 (0.29 - 5.08)	-
	bottom-up	41/147 (27.9%)	9/30 (30%)	1.03 (0.49 - 2.64)	-
Competitive History					
8.6 or more years of competitive experience at u23	top-down	7/40 (17.5%)	8/12 (66.7%)	6.6 (2.1 - 33.88)	High
	bottom-up	11/147 (7.5%)	8/30 (26.7%)	3.94 (1.66 - 12.1)	Moderate
Competed in at least 8 events at u23	top-down	8/40 (20%)	6/12 (50%)	3.05 (1.02 - 14.37)	Moderate
	bottom-up	13/147 (6.8%)	10/30 (20%)	4.56 (2.01 – 12.9)	Moderate
Competed in a British senior event at least 2 times at u23	top-down	12/40 (30%)	10/12 (83.3%)	7.18 (2.07 - 44.28)	High
	bottom-up	21/147 (14.3%)	15/30 (50%)	5.37 (2.54 - 13.62)	High
Won at least a silver medal at a British senior event at u23	Top-down	15/40 (37.5%)	8/12 (66.7%)	2.5 (0.84 - 11.46)	-
	Bottom-up	32/147 (21.8%)	14/30 (46.7%)	2.87 (1.4 - 6.99)	Moderate
Competed in a world senior event at least 1 time at u23	top-down	1/40 (2.5%)	3/12 (25%)	5.85 (1.26 - 74.59)	Moderate
	bottom-up	3/147 (2%)	9/30 (30%)	14.73 (4.94 - 67.4)	High

Supplementary Information: Chapter 3

A retrospective enquiry into the holistic development of elite British weightlifters

The aim of this supplementary document is to present:

1. The information sheet given to all participants prior to the study
2. The interview transcript for the full retrospective interview
3. The results for the full analyses from each section of the interview

1. Participant Information Sheet

Bangor University, George Building, Bangor, Gwynedd LL57 2PZ
Weightlifting Wales, Canoflan Brailsford, Ffriddoedd Road, Gwynedd LL57 2EH

Participant Information Sheet

The biographical development of Elite British Weightlifters

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Invitation to take part in the study

You are being invited to take part in a research study. Before you agree to take part it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. If you wish, discuss it with friends and relatives. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether you wish to take part, or not.

What is the purpose of this research?

The research is trying to answer the '*what makes the difference?'* question. Why do some weightlifters develop into international athletes and others into domestic athletes?

Of course, the World's best weightlifters are born with unique qualities, but these are honed with practice. This study will provide a unique, in-depth investigation of the practice and competitive biographies of Britain's best weightlifters from the past 15 years. This project takes talent research to the next level, and is 100% bespoke to weightlifting. The benefit to Weightlifting Wales will be to inform a KESS 2 funded national Talent Identification project, Weightlifting Wales Coach Development programmes, and the Development Pathway programme content and strategy.

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are free to withdraw at any time and without giving a reason.

What will happen to me if I agree to take part?

The research involves detailed interviews with a group of 'super elite' British Weightlifters with a matched (twin) group of domestic weightlifters who have achieve peak performance at a similar age. After the interview, the responses will be coded into data and state of the art analytics will determine the critical factors. The 3-hour interview consists of 4 sections:

Section 1: Demographic information (family, home place & education)

Section 2: Volume of practice and competition in weightlifting and other sports

Section 3: Milestones reached in represented competitions by ages 12, 15, 19 and 23

Section 4: The details of your weightlifting practice history

The interview will also contain a short list of additional questions at the end of the interview. These questions are open-ended and are intended to allow the researcher to understand your development from a broad perspective, which may not directly relate to weightlifting (discussed in the next section).

Dior Anderson, the researcher working with Weightlifting Wales and Bangor University, will be conducting the interviews.

What are the possible disadvantages and risks of taking part?

The majority of the interview will focus on your practice, training and competitive development in weightlifting and does not present any major risks to you as the participant. However, there are questions at the end of the interview which may pose some psychological risks to you. This is of course dependent on the nature of the information you disclose. For example, one question will relate to any negative life events you may have experienced during your developmental years, such as the death or illness of a family member or friend. It is broadly advised that you do not disclose any illegal or criminal activity, but you may wish to disclose any critical life events that were a part of your development (please also be advised that under circumstances in which information is disclosed that could be of potential harm to the welfare of others, we will need be report this to the relevant authorities). Given the sensitive nature of such topics, you may not wish to disclose such information at all and would prefer not to be asked questions of this manner during the interview. In such case, you are free to opt out of being asked questions about sensitive information by selecting this option when completing the informed consent form provided. You are also free not to answer such questions as you see necessary during the interview. In the event that you are happy to disclose such information, our researcher will advise you on the steps to take for additional support, following the interview.

What are the possible benefits of taking part?

The outcome of the study will provide Weightlifting Wales with an evidence base from the developmental biographies of Britain's best weightlifters, the discovery of new information which could potentially benefit the long-term development of future athletes. In addition, the outcome of the study will support the provision of high-quality education for coaches and sports performance practitioners.

Confidentiality

All information which is collected about you during the course of the research will be kept strictly confidential. The interviews will be recorded for transcription purposes. The recordings will be transcribed by professional transcribers before being deleted. The transcriptions will then be interpreted and analysed by our research team. The School of Sport, Health, and Exercise Sciences at Bangor university will have custody over the transcriptions, which will be kept in a password protected computer and in a locked filling cabinet at the school for future analyses once the study is over. Any information which leaves the School will have your name and address removed so that you cannot be recognised from it. It will not be possible to identify you in any report or publication of the study.

Who is organising or funding the research?

The research is organised by the Knowledge Economy Skills Scholarships (KESS), which is a pan-Wales higher level skills initiative led by Bangor University on behalf of the HE sector in Wales. It is part funded by the Welsh Government's European Social Fund (ESF) convergence programme for West Wales and the Valleys.

Who has reviewed the study?

The study has been reviewed by the SSHES ethics committee and has been identified as containing more than minimal risk to the participant. As mentioned above, this is entirely dependent upon the nature of information disclosed during the interview. The researcher will provide you with additional support where necessary to ensure that the risks that are posed to you are appropriately mitigated.

Feedback on Conduct of Research

SSHES is always keen to hear the views of research participants about their experience. If you would like to feedback, please ask your researcher to provide you with Form 6 – Participant Feedback Form – from the Ethics Guidelines Handbook. Completion of this form is optional. The completed form should be returned to Anthony Blanchfield, Chair, SSHES Ethics Committee, SSHES, Bangor University, Bangor LL57 2PZ. All information will be treated in a strictly confidential manner.

Any Questions?

Please ask us if you have any questions. You should not sign the form consenting to take part in the study if you still have unanswered questions or any doubts.

Requesting your participation:

As one of a relatively small number of elite British weightlifters, we would very much appreciate your involvement in this research. Please confirm your willingness to participate by completing and returning the informed consent form provided to Simon Roach at simon.roach@weightlifting.wales or by post on the address provided in the header of this information sheet , who will then contact you to arrange an appointment with Dior at your convenience.

2. Interview transcript for retrospective interview

Interview Procedures:
WW Attainment of Expertise Project

Introduction

This interview is designed to provide information about your long-term involvement in Weightlifting plus background information about your developmental sporting history. It consists of four major sections. The first section focuses on demographic and family information. The second section deals with your general participation in sporting activities. Thirdly, I ask about developmental milestones and performance indicators in weightlifting throughout your development. The first three sections will be a lot of number collecting, so please do bear with me for the first hour. The final section centres on your specific practice activities and time commitment to different aspects of your weightlifting training. This is where I'll be asking about the bulk detail of your practice, and I'll try to keep us both on track in the early stages so that it moves smoothly and I don't take up more of your time than is necessary.

1. Demographic and Family Information

Personal Details

<Section 1 – Demographic Family>

Homeplace Throughout Development

I'll now be listing some ages to you, starting with 6 up to 22. Please could you tell me (from earliest to most recent) all the places where you have lived and indicate for each the approximate dates/years you were at each place? For each place you lived indicate if it was your family home and if your home location was considered rural, small town, small city, or large city.

[NB: If you were living away from home for a portion of the year at boarding school etc. please note this in the next question rather than this one.]

<Table 1.1: Places you lived>

Education Throughout Development

Similarly, please could you list to me (from earliest to most recent – by age again) all the schools/colleges/universities you have attended and indicate for each the approximate dates/years you attended them. We also ask you to tell us if the place you went to school was a "designated" sport school and if it was the principal place where you practiced sport.

<Table 1.2: Places you went to school>

2. Activities throughout the Lifespan

Involvement in Sports

<Table 2: Involvement in Sport>

REPEAT THIS ACCORDING TO SPORT… ACROSS THEN DOWN

In this next section, we would like to focus on sports that you were involved in throughout your development – this includes all sports and sporting activities that may not necessarily be classified as a sport (e.g. multi-skill games) that were either led or not led by an adult. Firstly, I'd like you to look back over your entire life and list any type of sporting activity that you engaged in on *a regular basis* from the earliest point you can remember. Please list to me ALL the sports/sporting activities you participated in starting as early as age 6 and continuing up until age 22.

< Table 2, fill in the first column, "sports">

I would now like you to tell me ages from when you started playing the sport to ages where you stopped. You may have stopped temporarily, in which case please also tell me when you restarted. *(Interviewer place an "X" in any of the boxes corresponding to ages that interviewee was NOT involved in the sport listed). For example, if the interviewee mentioned football, but only played from age 6 to 12, put X's in boxes corresponding to ages 13-22. Do this for each sport listed.*

<Table 2, put an X for each age that interviewee was NOT involved in the listed sports>

Now, considering that weightlifting is your primary sport, I'd like you to tell me which two sports were your other 'major' or 'significant' ones.

<Table 2, put an * to identify the two major/significant sports>

O.K., for the rest of this section we are going to focus on weightlifting. Firstly, starting from when you began weightlifting at age __, can you define the time period in months in which you were involved in weightlifting. It is important that you tell me when these changed during the different ages as you progressed in your development, as we go through this in due course.

< Table 2 Fill in time of period for weightlifting >

Now can you recall a typical week for your weightlifting involvement at age ___ and tell me the number of hours you were engaged in weightlifting specific training per week. Please bear in mind that practice in this case is outside of competition and is specific to practicing the competitive weightlifting lifts (i.e. the Snatch and Clean & Jerk) and includes any weightlifting specific technique exercises where you are using the Olympic barbell (e.g. primary assistance exercises such as the snatch-grip deadlift and mobility exercises such as the overhead squat). Practice could include individual practice without a

coach, individual practice with a coach, plus any other type of weightlifting specific practice that you may have experienced.

< Table 2 Fill in practice hours/week for weightlifting specific practice at relevant age listed>

In addition, can you recall the number of hours per week you engaged in strength and conditioning training at age__. This includes the use of secondary assistance exercises such as Plyometric, Gymnastic, Callisthenic, Barbell & Dumbbell exercises that are non-weightlifting specific. This does not include any mobility exercises or weightlifting specific technique drills or exercises.

< Table 2 Fill in strength & conditioning hours/week for weightlifting at relevant age listed>

Also, I would like you to recall the number of hours per week you engaged in flexibility and/or mobility training at age __ that was non-specific to weightlifting. This could include any specific stretching and self-myofascial release exercises tailored to increasing joint range of motion.

< Table 2 Fill in flexibility and/or mobility hours/week in weightlifting at relevant age listed>

Now, still at age __, I'd like you to tell me the number of structured weightlifting competitions you engaged in throughout the year.

< Table 2 Fill in number of weightlifting competitions per year>

Of the number of competitions in which you had competed in at age__, I would now like you to recall the total number of hours you spent in competition across the year. Please consider any competitions in which you may not have recorded a total lift, became injured during competition, or anything else that may have shortened the amount of time spent in a competition.

<Table 2 Fill in number of hours in competitions per year>

<u>Question – Deliberate Practice vs. Deliberate Play (All Sports)</u>

< Table 2.1 >

Before we move onto the next section, I have a more general question about your participation in all of these sports you have mentioned (as a whole).

Between the ages of 6 and 13, firstly, I'd like you to consider the amount of time in that typical week that consisted of practice activities that were effortful, focused, goal directed, and not inherently enjoyable (deliberate practice). Now, I'd also like you to consider the amount of time that consisted of practice activities that were fun, voluntary, developmentally free from specific

focus, and provided immediate gratification (deliberate play). Now please split the proportion of time (in percentage) of your typical week between these two practice types for when you were between 6 and 13 years of age.

< Table 2.1 Fill proportion of Deliberate Play and Practice between ages 6 and 13>

Please can you also split the proportion of time (in percentage) again between these two practice types (deliberate play and deliberate practice), but now for when you were between the ages of 13 and 15?

< Table 2.1 Fill proportion of Deliberate Play and Practice between ages 13 and 15 >

Now I would like you to split the proportion of time (in percentage) again between these two practice types (deliberate play and deliberate practice), but now for when you were between the ages of 16 and 19?

< **Table 2.1 Fill proportion of Deliberate Play and Practice between ages 16 and 19 >**

Lastly, I would like you to split the proportion of time (in percentage) between these two practice types (deliberate play and deliberate practice), but now for when you were between the ages of 20 and 22?

< **Table 2.1 Fill proportion of Deliberate Play and Practice between ages 20 and 22 >**

3. Developmental Milestones, Performance Indicators and Maturation in Weightlifting

<Table 3 - Performance at different ages>
DO ACROSS THEN DOWN

In this section of the questionnaire I would like you to focus specifically on your development in weightlifting. I would like to get a sense of your development in weightlifting by assessing different milestones that you may have achieved. I am going to be asking you questions across specific developmental stages (ages) which will aim to measure your level of performance and the challenges faced as you developed as a weightlifter at each stage specified. The first developmental stage will be by age 12. I will now ask you a series of questions associated with this age group, and then we will repeat this process for up to 15 years, up to 19 years, and finally your weightlifting by 23.

Firstly, by 12, I would like you to tell me the name of the competition, the age group and the weight category classification in which you **first** competed at the highest level of competition for the following representation levels in weightlifting, there may be some that do not apply to you, in which case just let me know: *(Interviewer reminds interviewee that these questions correspond to when they were **by 12/by 15/by 19/by 23** years of age and subsequently reports the age that corresponds to each of the levels listed in table 3).*

- Local/inter-club/Developmental
- Regional
- National
- British
- International
- Olympic

<Fill in Competitions, Age group and Weight Category on Table 3 in Spreadsheet>

Now I would like to ask you some questions about each competition you have listed in a little more detail. Starting with the date of the first competition, I would like you to recall the month and year that this competition took place *(Interviewer reminds interviewee that these questions correspond to each age when they were **by 12/by 15/by 19/by 23** years of age and subsequently reports the age that corresponds to each of the levels listed in table 3)*.

<Fill in date of competition for each competition listed in table 3>

Additionally, for each completion you have listed, I would like you to recall whether or not you were aiming for peak performance. Aiming for peak performance means that you structured your training frequency, load, and volume leading up to the competition in such a way that you aimed to be in the best possible condition for the competition. *(Interviewer lists competitions age group, weight category, whether or not peak performance was aimed for)*

<Fill in peak performance on Table 3 in Spreadsheet >

Finally, I would like you to recall the rank position you had finished on the day of each competition you had listed. *(Interviewer reminds interviewee that these questions correspond to each age when they were **by 12/by 15/by 19/by 23** years of age and subsequently reports the age that corresponds to each of the levels listed in table 3)*.

<Fill in Rank position for each competition listed in Table 3>

I would now like to ask you about the technical challenge of competing at each competition when you were age __. E.g. thinking about lift selection and execution; for someone lifting up an age group the technical challenge might be executing lifts with a heavier load with a higher success rate or with better technique. How technically challenging was it for you at this level? To do this, please rate challenge from 1 – 10, with 1 being the easiest rating and 10 being the most challenging rating. (*Interviewer lists individual weightlifting age groups the interviewees had previously reported lifting in and simultaneously reports the level of challenge noted for each age group in table 3).*

<Fill in rated Technical Challenge on Table 3 in Spreadsheet >

I would now like to ask you about the psychological challenge of lifting at this level when you were first selected at age _. Using the same example of executing lifts with heavier loads or with a higher success rate, the psychological challenge might be the fear of being technically inferior to your competition peers or the fear of failing a lift in front of a big crowd and/or parents. To do this, please rate challenge from 1 – 10, with 1 being the easiest rating and 10 being the most challenging rating. *(Interviewer lists psychological challenge for each competition competed in at age group listed in table 3)*

<Fill in Psychological Challenge on Table 3 in Spreadsheet >

Next, I would like to ask you about your ability compared to your peers at your main training venue. Specifically, in your opinion, were you one of the best weightlifters at your venue when you were preparing for …….. competition? *(Interviewer records the 'yes' or 'no' response of the interviewee in the 'one of the best' column in table 3 at the relevant competition)*

<Fill in one of best weightlifters at main training venue on Table 3 in Spreadsheet >

Similarly, I would now like you to tell me in your opinion, were you the best weightlifter at your main training venue when you were preparing for ……..competition at age …..? *(Interviewer records the 'yes' or 'no' response of the interviewee in the 'the best weightlifter' column in table 3 at the relevant competition)*

<Fill in best weightlifter at main training venue on Table 3 in Spreadsheet >

Now I would now like you to tell me about your physical size in comparison to firstly your competition peers and then your training peers at this particular age and competition. Please tell me if you were of greater physical size (G), smaller (S) or equal (E) to your competition and training peers when you were preparing for ……..competition at age ……. *(Interviewer records the responses related to physical size on Table 3).*

<Fill in physical size for competitors and training peers at main training venue on Table 3 in Spreadsheet >

Lastly, for this milestone, I would like you to recall the development time (in months) that you missed due to prevalence of injuries by age 12. Please note that these can be cumulative, therefore feel free to take some time to think about this. By age 12, if you never had an injury, please rate fitness at 100%. *If you did suffer an injury try to rate the percentage of full fitness for me (i.e. completely unable to train or compete in this time would receive a rating of 0, missing half the time would receive a rating of 50% and so on…).*

(Interviewer lists the prevalence of injuries by 12, 15, 19 and 23 years of age and simultaneously records nature of injury).

<Fill in injury time/nature>.

Milestones/Obstacles

<Section 3.1>

Finally, for this section, I would like get a sense of your development in weightlifting by assessing different milestones that you may have achieved together with different obstacles you may have overcome. For each of the questions I ask, please tell me the age at which the specific event occurred for you. If the event did not occur, then please tell me so.

Firstly, how old were you when you first moved (relocated) to attend regular weightlifting training?

<Interviewer records years old when first moved to attend regular weightlifting training in section 3.1 on spreadsheet>

How old were you when you first established a close and extended relationship with a Weightlifting coach?

<Interviewer records 'years old when you first established a close and extended relationship with a Weightlifting coach' in section 3.1 on spreadsheet>

Were you ever taken out of a weightlifting academy? If so, how old were you? How old were you when you got reselected? Did this ever get repeated? When?

<Interviewer records 'years old when years and months old when first deselected', 'years and months old when reselected', 'times repeated' and 'repeated at ages' in section 3.1 on spreadsheet>

Did you ever get dropped (having become a regular) from a national weightlifting academy? If so, how old were you? How old were you when you got reselected? Did this ever get repeated? When?

<Interviewer records 'years old when years and months old when first deselected', 'years and months old when reselected', 'times repeated' and 'repeated at ages' in section 3.1 on spreadsheet>

Did you ever get dropped from Great Britain? If so, how old were you? How old were you when you got reselected? Did this ever get repeated? When?

<Interviewer records 'years old when years and months old when first deselected', 'years and months old when reselected', 'times repeated' and 'repeated at ages' in section 3.1 on spreadsheet>

4. Practice Activities in Weightlifting

What follows is a section in which we want to trace your involvement in the different types of practice possibilities during your weightlifting development. The following section includes segments for the related practice activities you engaged in, the proportion of time spent practicing per week, the intensity of practice, and the nature of practice activities. Specifically, we will be focusing on a typical week's practice that was specific to the technical development of the competitive lifts in weightlifting (i.e. the snatch and clean & jerk) across each of the four age milestones we focused on in the previous section. *(Interviewer reminds interviewee of the four different age milestones; Ages 12, 15, 19 and 23.*

MILESTONE 1: …… Years old

Firstly, let's start with when you were weightlifting at …… years of age. If I refer to your responses in section 2 of this interview (refer to table 2 and look the amount of hours of practice that are listed for

weightlifting at age .....), I can see that at ……. you stated that you completed …… hours of training per week. So, I'd like you to consider the rest of this section in line with a typical week's practice when you were aged ....., which may include any of the following; individual practice without a coach, individual practice with a coach, plus any other type of weightlifting practice that you may have experienced.

Deliberate Play vs. Deliberate Practice
<Table 4.1a>

Firstly, I'd like you to consider the amount of time in that typical week at age ..... that consisted of practice activities that were effortful, focused, goal directed, and not inheritably enjoyable (deliberate practice). Now, I'd also like you to consider the amount of time that consisted of practice activities that were fun, voluntary, developmentally free from specific focus, and provided immediate gratification (deliberate play). Now please split the proportion of time (in percentage) of your typical week between these two practice types.

Mental Skills Training

O.k., now considering your typical week when you were ..... years of age, please could you tell me how many hours during that typical week you engaged in mental skills training practice (e.g., visualisation skills, working out pre-performance routines, relaxation or concentration techniques etc.).

< Table 4.1b Interviewer subsequently records mental skills training hours >

Vicarious Learning
I would now like you to recall how many hours during the typical week you engaged in learning through watching weightlifting (e.g., watching weightlifting on T.V., watching other weightlifters' practice and/or playing in order to increase you own skill).

< Table 4.1c Interviewer subsequently records vicarious experiences hours >

Conveying of Information
<Table 4.1d>

Now, I'd like to find out about what your physical weightlifting practice was like for you during the same typical week. When recalling information, I'd like you to draw from all the different practice possibilities you experienced. For example, individual practice without a coach, individual practice with a coach, plus any other type of weightlifting practice that you may have experienced during that typical week

Taking into consideration all of the practice you did in a typical week when you were ....., I would like you to first consider how instructions about technique, strategy, and your performance were presented to you.

Was that information ever presented in verbal form?
<If YES interviewer places a "Y" in conveying information column, if NO places an "N">

Was that information ever presented via a demonstration?
<If YES interviewer places a "Y" in conveying information column, if NO places an "N">

Was that information ever presented in video form?
<If YES interviewer places a "Y" in conveying information column, if NO places an "N">

< Table 4.1d Fill in above conveying information practices>

Now please can you split the individual proportions of practice time where the instructions you received about technique, strategy, and your performance were given 1) verbally, 2) via demonstration, and 3) via

video? *(interviewer only asks about those that were indicated in the previous question)*. Please use 100% as all of the time and split that way. *(Interviewer records number in Table 4.1d).*

<Fill in conveying information prevalence Table 4.1d>

STRUCTURING PRACTICE

I'm interested in your practice structure and I've got a grid here that I'd like to go through with you. This grid allows me to create a visual representation of how your practice was structured for each of your competitive lifts at age ……. Specifically, we will focus on whether you practiced each lift as the whole movement (i.e. from start to finish), in parts of the whole movement, or a combination of both. Also, I would like to understand how you sequenced these movements within the structure of your practice session.

To keep things straightforward, I have separated the Snatch, the Clean and Jerk as individual lifts. There may have been instances where you practiced these lifts (or parts of each lift) together, in which case we will include this information when I ask about your practice structure. Again, try to recall a typical weeks training session when you were in the most technical phase of your programme that focused on the development of your movement.

Whole/Part

Let's start with how you would have broken down the Snatch in practice at age …… Along the top of the table I have separated the snatch into its general execution phases from the start of the lift to the finish position. The black lines beneath each phase title marks the start of each phase. Each row down from the top of the grid represents a different part in which you may have practiced the Snatch, and will be highlighted at the relevant start and finish points on the grid. Assuming that you would have practiced the Snatch as a whole movement (i.e. from start to finish), the first line will represent the movement as a whole; therefore I will highlight the first row on the grid inline from the start position marker to the finish position marker (i.e. the whole column). In the extreme left-hand column, I will label this representation 'S1' for the first part of the Snatch movement that we have listed; subsequent parts will be labelled S2, S3, S4 and so on. To keep us on track visually, I would like you to tell me the next part you would have broken the lift down starting from the most bottom part (i.e. from the start of the lift); we will then work our way up from there.

<Interviewer records each part of the Snatch lift in the section of the grid labelled Snatch Lift>

Next I would like to repeat this process for the Clean and Jerk. Again, I have broken each lift down into its relevant phases along the top. We will start by highlighting the first column as the whole movement; and will label this representation 'CJ1' in the extreme left-hand column. Next, I would like you to tell me any additional part of the Clean and Jerk you practiced in a typical weeks training by age ……. Again, we will start from the most bottom part of the lift and work our way up from there.

<Interviewer records each part of the Clean lift in the section of the grid labelled Clean Lift>

Blocked/Random

Next, I am interested in how you would have sequenced the parts of each lift you have listed during practice. Specifically, I am in interested in whether you practiced each part repeatedly for a set amount of lifts before moving onto another part (i.e. blocked practice), or whether you practiced each part of the lift in a mixed order with another part of a lift (i.e. random practice).

Starting with the first part of the lift you had practiced with the snatch, labelled 'S1', I would like you to tell me the proportion of time you spent practicing this lift in a blocked manner.

Additionally, I would like you to tell me the proportion of time you spent practicing this lift that was random. If you had practiced each part of the lift randomly with another part of a lift, I would also like to know which parts of the lift you had typically practiced together in this way. For example, if you had practiced this part of the lift with another part that was related to the snatch (i.e. S2 or S3 and so on), then I would like you to label it here. If you had practiced this part with a part of another lift (e.g. CJ1, CJ2), then I would also like you to label it here.

<Interviewer records blocked vs. random practice for each part listed in previous section>

<***Lifts are typically defined as;*** *Snatch, Hang snatch, Hang Power Snatch, Overhead Squat, Snatch Balance, Heave Snatch Balance, Wide Grip Deadlift, Halted wide grip pull/bar at knee height, Clean & Jerk, Hang Clean, Hang Power Clean, Front Squat, Back Squat, Halted clean grip pull/bar at knee height, Power Jerk, Push Press, Dip and Drive>*

CONSTANT vs. VARIED PRACTICE
<Table 4.1e>

I would like you to think about the percentage of time in which the practice conditions during a typical weeks training at age …… were kept fairly constant. This includes maintaining a consistent practice environment, in which you practiced on the same platform, practiced with the same equipment and practiced the same routine. In contrast, I would like you to compare this to the percentage of time in which you varied your practice conditions in such a way that you practiced in a different environment, practiced on different surfaces or with an entirely different routine. This could have occurred deliberately or accidently, perhaps as a result of practicing in a new environment.

What percentage of time spent practicing at age..... was kept constant?

What percentage of time spent practicing at this age was varied?

SPECIFICITY AND DIFFICULTY OF PRACTICE
<Table 4.1f>

Context Specificity:

I would now like you to rethink about what practice was like in your typical week when you were ..... years of age. Now I would like you to consider whether practice environments were similar to the competition environment. Examples are situations where practice environments mirror competition closely, that is, setting (possibly imaginary) fields and creating scenarios that were likely to occur in competition. Perhaps your ordering of lifts and rest between lifts were timed in such a way that it replicated competition; or maybe you were lifting the same weight in practice you were likely to be lifting in the next competition. Please also try to recall situations where these examples might have happened ‘accidentally’, for example (during a typical transition week) you may have been practicing with more than one club and thus been exposed to more than one type of practice environment.

Based on the types of examples just spoken about, what proportion of your practice was similar to competition at age ……? (0% = never; 100% = all the time)

< Table 4.1e fill in Context Specificity >

Context Specificity Difficulty:

Please can you tell me how difficult (1-10) these sorts of 'competition scenario' sessions typically were at ..... years of age? *(Interviewer records difficulty on Table 4.1e)*

< Table 4.1e fill in Difficulty >

Anxiety Specificity:

Finally, in regards to practice matching competition, for your typical week when you were ..... I would like you to consider what the stress of practice was like in comparison to that of competition. Please pay particular attention to practices where pressure to perform was introduced. Examples of such practice could be the introduction of consequences to performances deemed unsuccessful (e.g. the deselection from a squad or a competition by your coach). Please tell me what proportion of your practice was set up so that the pressure induced was similar to that of competition (0% = never; 100% = all the time). *(Interviewer reports frequency on Table 4.1e)*

< Table 4.1e Fill in Anxiety Specificity >

Anxiety Specificity Difficulty:

Please can you tell me how difficult this pressured practice typically was at age .....? *(Interviewer records difficulty on Table 4.1e)*

< Table 4.1e Fill in Anxiety Specificity Difficulty >

<u>Pressure Induced Specificity</u>
<Recorded>

Finally, in regards to situations where you practiced in a pressured environment, can you provide me with some details about how pressure was induced?

<Interviewer records this for qualitative analysis>

<u>Focus of Attention</u>
<Table 4.1g>

O.K., I now want you to spend a little more time thinking about what your typical week was like when you were ..... I would like you to consider where your focus of attention was during practice. There are two types of situation that I would like you to consider:

1. Situations where you focused on your body (e.g., you may have been asked by your coach you to focus on your hands or to move your feet and your head in a certain direction when lifting ……or you may have focused on keeping your elbows up).
2. Situations where you focused on the outcome of your movements (e.g., when you may have been asked by your coach or you decided to focus on the movement or trajectory of the bar or the height of the bar during the lift and at the finish position).

Please can you now tell me how the proportion of time during practice where you focused on your body movements during training, compared to when you focused on the outcome of your movements? (0% = never; 100% = all the time)? *(Interviewer reports frequency on Table 4.1f)*

< Table 4.1f Fill FOA prevalence during practice >

<u>FOA nature</u>

<Table 4.1h>

For both the body and outcome focuses you just told me about, I would now like you to recall whether the majority of that focus was on the separate aspects of a technique/skill (e.g., when you broke the technique down into parts *such as the movement and position of the elbow, the movement of the feet, the trajectory of the bar at the end of the lift, the rotation of the wrists, or the position of head etc.*) or whether they were more holistic and focused on the technique as a whole (*e.g., movement of the body, trajectory of the bar for the whole lift*). *Interviewer records the responses on chat 4.1f; Place a 'p' if interviewee reports that the majority of their focus was on separate or individual aspects of a skill or place an 'h' if the focus was more holistic in nature. In situations where it is 50:50, place an 'e.*

< Table 4.1f Fill in FOA nature column; P/H/E>

<u>Intrinsic/Extrinsic Feedback</u>
<Table 4.1i>

Again, thinking back to your typical week when you were ..... , I would like you to tell me about the opportunities during practice that allowed you to develop your own feedback. For example, instances where you might only be given feedback when you asked your coach/peers for it? Or where your coach/peers asked you to describe what a lift felt like or how you could improve performance before giving you feedback? Maybe you were provided feedback after a period of delay? Maybe you just generated your own feedback a lot of the time…

Compare this with times where your coach would be providing constant feedback, without allowing delay for you to think about this yourself.

Please tell me what proportion of practice contained these types of feedback activities (i.e., activities where you afforded times to think about your own feedback before being provided it by a coach or peer, or where feedback was purely self-generated), compared to the times where feedback was actively given to you continuously during your practice (0% = never; 100% = all the time). *(Interviewer records intrinsic/extrinsic feedback prevalence on Table 4.1g)*

< Table 4.1g Fill in Intrinsic/Extrinsic Feedback >

<u>Constraints/Prescriptive Learning Approaches</u>
< Table 4.1j>

Finally, for your typical week at age ….., I would like to understand how often practice encouraged you to learn weightlifting skills with a prescriptive coaching approach versus a task based coaching approach. To help you recall this first let's discuss what a prescriptive coaching approach looks like and what a task based coaching approach looks like.

Prescriptive coaching typically involves lots of demonstrations and verbal instructions about how to perform a lift in a technically correct fashion together with lots of feedback and guidance about how to adjust this technique on future attempts.

Constraints based coaching typically involves creating situations where learners are encouraged/forced to find solutions to weightlifting scenarios through exploration and discovery. In a little more detail, these scenarios are created by

1. Manipulating the task (such as the conditions imposed by the coach [e.g., you can lift only to shoulder height or you can only drop below the bar to receive])
2. Manipulating the environment such as the height and/or space available on the lifting platform, the lifting surface, or lifting equipment.

3. Manipulating you as a lifter, perhaps by limiting your movement (e.g., with the use of ropes or elastic bands, or by manipulating your clothing and footwear attire).

In constraints-based coaching, when these types of manipulations have been imposed by the coach, or maybe even by yourself, your lifting movements change as a result of these and *not* as a result of the coach 'telling you what and how to do things'.

Now, with your understanding of prescriptive and task-based coaching, can you please tell me how much of your practice (%) during your typical week when you were ..... consisted of prescriptive coaching and how much consisted of task-based coaching. There may have been times where practice fell into neither of these categories and coaching was actually non-prescriptive and non-directional meaning you were left to your own devices, where you did NOT set your own task constraints, in which case just let me know. *(Interviewer records proportion of time on Table 4.1k)*

< Table 4.1k Fill in proportion of coaching approaches >

Key Learning experience
<Excel Sheet>

Finally, I would like you to think about whether there was a key learning experience that took place by age .....? It doesn't necessarily have to be at ..... years, it could be a few years earlier. This is open to your interpretation, but please be as specific as possible- stating why you think this was key.

< Interviewer records for qualitative analysis >

3. Odds ratio estimations for all logical attributes in retrospective analysis

Table 36. Odds ratio estimation for logical attributes in the demographics and family sport participation section

Attribute	Non-Elite	Elite	OR (95% CI)	Importance
Homeplace throughout development				
Population of longest residing homeplace between 6 to 12 years over 6,392	7/12 (58.3%)	11/11 (100%)	6.88 (0.81 - 351.79)	High
Population of longest residing homeplace between 13 to 15 years over 6,246	7/12 (58.3%)	10/11 (90.9%)	3.12 (0.67 - 39.25)	-
Population of longest residing homeplace between 16 to 19 years over 12,929	3/12 (25%)	5/11 (45.5%)	1.61 (0.43 - 12.21)	-
Density of longest residing homeplace between 6 to 12 years over 912.49	9/12 (75%)	11/11 (100%)	3.3 (0.39 - 185.35)	-
Density of longest residing homeplace between 13 to 15 years over 1460.12	2/12 (16.7%)	6/11 (54.5%)	3.33 (0.83 - 29.63)	-
Density of longest residing homeplace between 16 to 19 years over 619.51	12/12 (100%)	8/11 (72.7%)	0 (0 - 2.13)	-
Relocated at least once throughout formative years	4/12 (33.3%)	7/11 (63.6%)	2.24 (0.61 - 16.14)	-
Familial Sport participation				
Father involved in sport	11/12 (91.7%)	8/11 (72.7%)	0.17 (0.04 - 2.61)	-
Father experience in weightlifting	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Mother involved in sport	10/12 (83.3%)	8/11 (72.7%)	0.36 (0.09 - 3.71)	-
Mother experience in weightlifting	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Same sex sibling	6/12 (50%)	6/11 (54.5%)	0.86 (0.25 - 5.69)	-
Same sex older sibling	5/12 (41.7%)	3/11 (27.3%)	0.39 (0.11 - 2.96)	-
Same Sex Sibling experience in weightlifting	2/12 (16.7%)	0/11 (0%)	0 (0.01 - 4.26)	-
Schooling				
School main place for sport participation between 6 and 12 years	5/12 (41.7%)	6/11 (54.5%)	1.17 (0.33 - 7.83)	-
School main place for sport participation between ages 13 and 15	7/12 (58.3%)	4/11 (36.4%)	0.31 (0.09 - 2.19)	-
Relative Age				
Calendar Birth Quarter over 1	10/12 (83.3%)	10/11 (90.9%)	0.91 (0.19 - 15.01)	-
School Birth Quarter over 1	6/12 (50%)	8/11 (72.7%)	1.71 (0.47 - 12.68)	-
Relative age to nearest aged sibling more than 438 days	2/12 (16.7%)	5/11 (45.5%)	2.38 (0.6 - 21.21)	-

Table 36. Odds ratio estimations for all logical attributes in the sport participation history and weightlifting specific involvement section

Attribute	Non-Elite	Elite	OR (95% CI)	Importance
Sport participation throughout development				

Number of sports sampled:				
Sampled at least 1 sport at age 6	10/12 (83.3%)	8/11 (72.7%)	0.36 (0.09 - 3.71)	-
Sampled at least 1 sport at age 7	10/12 (83.3%)	9/11 (81.8%)	0.55 (0.13 - 6.43)	-
Sampled at least 1 sport at age 8	11/12 (91.7%)	10/11 (90.9%)	0.42 (0.08 - 10.19)	-
Sampled at least 1 sport at age 9	12/12 (100%)	10/11 (90.9%)	0 (0.01 - 7.62)	-
Sampled at least 2 sports at age 10	7/12 (58.3%)	3/11 (27.3%)	0.21 (0.06 - 1.59)	-
Sampled at least 3 sports at age 11	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Sampled at least 3 sports at age 12	1/12 (8.3%)	4/11 (36.4%)	2.75 (0.58 - 36.24)	-
Sampled at least 3 sports at age 13	2/12 (16.7%)	4/11 (36.4%)	1.67 (0.41 - 15.37)	-
Sampled at least 3 sports at age 14	1/12 (8.3%)	3/11 (27.3%)	1.83 (0.38 - 25.99)	-
Sampled at least 2 sports at age 15	7/12 (58.3%)	4/11 (36.4%)	0.31 (0.09 - 2.19)	-
Sampled at least 2 sports at age 16	5/12 (41.7%)	2/11 (18.2%)	0.23 (0.06 - 2.12)	-
Sampled at least 2 sports at age 17	3/12 (25%)	4/11 (36.4%)	1.12 (0.3 - 8.86)	-
Sampled no more than 1 sport at age 18	10/12 (83.3%)	11/11 (100%)	2 (0.23 - 127.73)	-
Sampled no more than 1 sport at age 19	11/12 (91.7%)	11/11 (100%)	0.92 (0.11 - 81.61)	-
Sampled more than 3 different sports between 6-12 years	4/12 (33.3%)	5/11 (45.5%)	1.14 (0.32 - 8)	-
Sampled more than 3 different sports between 13-15 years	2/12 (16.7%)	4/11 (36.4%)	1.67 (0.41 - 15.37)	-
Sampled no more than 1 sport between 16-19 years	6/12 (50%)	5/11 (45.5%)	0.61 (0.18 - 4.08)	-
Years involved in each sport between 6 – 12 years:				
Athletics (no minimum)	5/12 (41.7%)	5/11 (45.5%)	0.83 (0.24 - 5.61)	-
Gymnastics for more than 2 years	4/12 (33.3%)	1/11 (9.1%)	0.15 (0.03 - 2.11)	-
Kung Fu (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Tennis (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Karate (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Horse Riding (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Kickboxing (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Trampoline (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Diving (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Hockey (no minimum)	1/12 (8.3%)	1/11 (9.1%)	0.5 (0.1 - 12.23)	-
Netball (no minimum)	2/12 (16.7%)	2/11 (18.2%)	0.67 (0.16 - 7.85)	-
Rugby (no minimum)	7/12 (58.3%)	4/11 (36.4%)	0.31 (0.09 - 2.19)	-
Football (no minimum)	2/12 (16.7%)	3/11 (27.3%)	1.11 (0.27 - 11.09)	-
Swimming (no minimum)	1/12 (8.3%)	2/11 (18.2%)	1.1 (0.22 - 18.19)	-
Team Sports (no minimum)	9/12 (75%)	7/11 (63.6%)	0.42 (0.11 - 3.34)	-
Individual Sport (no minimum)	6/12 (50%)	9/11 (81.8%)	2.57 (0.65 - 22.25)	-
CGS Sports for more than 1 year	5/12 (41.7%)	8/11 (72.7%)	2.33 (0.63 - 17.44)	-
Years involved in each sport between 13 – 15 years:				
CrossFit (no minimum)	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Athletics for more than 1 year	5/12 (41.7%)	5/11 (45.5%)	0.83 (0.24 - 5.61)	-
Gymnastics for more than 1 year	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-

Kung Fu (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Tennis (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Trampoline (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Diving (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Hockey (no minimum)	1/12 (8.3%)	2/11 (18.2%)	1.1 (0.22 - 18.19)	-
Netball (no minimum)	2/12 (16.7%)	2/11 (18.2%)	0.67 (0.16 - 7.85)	-
Rugby (no minimum)	7/12 (58.3%)	3/11 (27.3%)	0.21 (0.06 - 1.59)	-
Football for more than 2 years	1/12 (8.3%)	2/11 (18.2%)	1.1 (0.22 - 18.19)	-
Team Sports (no minimum)	9/12 (75%)	6/11 (54.5%)	0.3 (0.08 - 2.31)	-
Individual Sport for more than 2 years	5/12 (41.7%)	8/11 (72.7%)	2.33 (0.63 - 17.44)	-
CGS Sports for more than 2 years	4/12 (33.3%)	7/11 (63.6%)	2.24 (0.61 - 16.14)	-
Years involved in each sport between 16 – 19 years:				
CrossFit (no minimum)	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Athletics (no minimum)	1/12 (8.3%)	2/11 (18.2%)	1.1 (0.22 - 18.19)	-
Hockey (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Netball (no minimum)	1/12 (8.3%)	1/11 (9.1%)	0.5 (0.1 - 12.23)	-
Football (no minimum)	1/12 (8.3%)	2/11 (18.2%)	1.1 (0.22 - 18.19)	-
Team Sports (no minimum)	5/12 (41.7%)	3/11 (27.3%)	0.39 (0.11 - 2.96)	-
Individual Sport for more than 2 years	7/12 (58.3%)	11/11 (100%)	6.88 (0.81 - 351.79)	High
CGS Sports for more than 2 years	8/12 (66.7%)	11/11 (100%)	4.89 (0.57 - 257.96)	-
Weightlifting related involvement:				
Flexibility/mobility training (hours per week) at:				
Age 6 (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 7 (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 8 (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 9 (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 10 (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 11 (no minimum)	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Age 12 (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 13 more than 0.49 hours	1/12 (8.3%)	4/11 (36.4%)	2.75 (0.58 - 36.24)	-
Age 14 more than 0.56 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Age 15 more than 0.52 hours	1/12 (8.3%)	5/11 (45.5%)	3.93 (0.84 - 50.17)	-
Age 16 more than 2.02 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age 17 more than 2.67 hours	2/12 (16.7%)	3/11 (27.3%)	1.11 (0.27 - 11.09)	-
Age 18 more than 2.64 hours	1/12 (8.3%)	3/11 (27.3%)	1.83 (0.38 - 25.99)	-
Age 19 more than 2.61 hours	1/12 (8.3%)	4/11 (36.4%)	2.75 (0.58 - 36.24)	-
Strength & Conditioning Training (hours per week):				
Age 6 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 7 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 8 more than 0.1 hours	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Age 9 more than 0.1 hours	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-

Age 10 more than 0.1 hours	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Age 11 more than 1.04 hours	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Age 12 more than 0.91 hours	2/12 (16.7%)	2/11 (18.2%)	0.67 (0.16 - 7.85)	-
Age 13 more than 1.55 hours	1/12 (8.3%)	3/11 (27.3%)	1.83 (0.38 - 25.99)	-
Age 14 more than 1.7 hours	3/12 (25%)	4/11 (36.4%)	1.12 (0.3 - 8.86)	-
Age 15 more than 1.99 hours	3/12 (25%)	5/11 (45.5%)	1.61 (0.43 - 12.21)	-
Age 16 more than 2.37 hours	2/12 (16.7%)	4/11 (36.4%)	1.67 (0.41 - 15.37)	-
Age 17 more than 2.4 hours	4/12 (33.3%)	7/11 (63.6%)	2.24 (0.61 - 16.14)	-
Age 18 more than 4.02 hours	2/12 (16.7%)	4/11 (36.4%)	1.67 (0.41 - 15.37)	-
Age 19 more than 4.01 hours	3/12 (25%)	4/11 (36.4%)	1.12 (0.3 - 8.86)	-
Weightlifting specific practice (hours per week):				
Age 6 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 7 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 8 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 9 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 10 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 11 (no minimum)	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Age 12 (no minimum)	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Age 13 more than 2.02 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age 14 more than 4.51 hours	1/12 (8.3%)	6/11 (54.5%)	5.5 (1.17 - 70.07)	Moderate
Age 15 more than 6.55 hours	1/12 (8.3%)	5/11 (45.5%)	3.93 (0.84 - 50.17)	-
Age 16 more than 9.13 hours	3/12 (25%)	4/11 (36.4%)	1.12 (0.3 - 8.86)	-
Age 17 more than 9.15 hours	2/12 (16.7%)	5/11 (45.5%)	2.38 (0.6 - 21.21)	-
Age 18 more than 10.44 hours	2/12 (16.7%)	4/11 (36.4%)	1.67 (0.41 - 15.37)	-
Age 19 more than 11.05 hours	2/12 (16.7%)	4/11 (36.4%)	1.67 (0.41 - 15.37)	-
Total combined flex/mob, strength & conditioning, and weightlifting specific practice (hours per week):				
Age 6 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 7 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 8 (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 9 (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 10 (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 11 more than 1.12 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age 12 more than 1.17 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age 13 more than 2.66 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Age 14 more than 4.34 hours	2/12 (16.7%)	8/11 (72.7%)	6.67 (1.59 - 65.39)	High
Age 15 more than 8.66 hours	1/12 (8.3%)	8/11 (72.7%)	11 (2.26 - 153.3)	High
Age 16 more than 12.49 hours	2/12 (16.7%)	7/11 (63.6%)	4.67 (1.15 - 42.68)	High
Age 17 more than 12.48 hours	2/12 (16.7%)	6/11 (54.5%)	3.33 (0.83 - 29.63)	-
Age 18 more than 19.63 hours	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Age 19 more than 20.01 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Competitions per year:				

Age 6 at least 1 competition	0/12 (0%)	0/11 (0%)	NA	NA
Age 7 at least 1 competition	0/12 (0%)	0/11 (0%)	NA	NA
Age 8 at least 1 competition	0/12 (0%)	0/11 (0%)	NA	NA
Age 9 at least 1 competition	0/12 (0%)	0/11 (0%)	NA	NA
Age 10 at least 1 competition	0/12 (0%)	0/11 (0%)	NA	NA
Age 11 at least 1 competition	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 12 at least 1 competition	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Age 13 at least 1 competition	1/12 (8.3%)	4/11 (36.4%)	2.75 (0.58 - 36.24)	-
Age 14 at least 2 competitions	1/12 (8.3%)	6/11 (54.5%)	5.5 (1.17 - 70.07)	Moderate
Age 15 at least 4 competitions	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Age 16 at least 6 competitions	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Age 17 at least 6 competitions	1/12 (8.3%)	4/11 (36.4%)	2.75 (0.58 - 36.24)	-
Age 18 at least 5 competitions	2/12 (16.7%)	3/11 (27.3%)	1.11 (0.27 - 11.09)	-
Age 19 at least 5 competitions	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Cumulative hours spent in competition (per year):				
Age 6 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 7 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 8 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 9 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 10 (no minimum)	0/12 (0%)	0/11 (0%)	NA	NA
Age 11 (no minimum)	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age 12 more than 0.41 hours	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Age 13 more than 2.52 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age 14 more than 1 hour	2/12 (16.7%)	7/11 (63.6%)	4.67 (1.15 - 42.68)	High
Age 15 more than 6.8 hours	3/12 (25%)	6/11 (54.5%)	2.25 (0.6 - 17.05)	-
Age 16 more than 6.65 hours	5/12 (41.7%)	7/11 (63.6%)	1.63 (0.46 - 11.31)	-
Age 17 more than 14.78 hours	5/12 (41.7%)	8/11 (72.7%)	2.33 (0.63 - 17.44)	-
Age 18 more than 14.14 hours	2/12 (16.7%)	6/11 (54.5%)	3.33 (0.83 - 29.63)	-
Age 19 more than 14.57 hours	2/12 (16.7%)	6/11 (54.5%)	3.33 (0.83 - 29.63)	-
Cumulative practice volumes by age 12:				
Flexibility/mobility practice over 25.03 hours	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Strength & Conditioning training over 32.48 hours	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Weightlifting specific practice over 16 hours	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Number of competitions over 0	2/12 (16.7%)	2/11 (18.2%)	0.67 (0.16 - 7.85)	-
Competition time over 0.49 hours	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Cumulative practice volumes by age 15:				
Flexibility/mobility practice over 106.93 hours	1/12 (8.3%)	7/11 (63.6%)	7.7 (1.62 - 100.67)	High

Strength & Conditioning training over 416.88 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Weightlifting specific practice over 552.97 hours	1/12 (8.3%)	7/11 (63.6%)	7.7 (1.62 - 100.67)	High
Number of competitions over 3	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Competition time over 31.31 hours	1/12 (8.3%)	5/11 (45.5%)	3.93 (0.84 - 50.17)	-
Cumulative practice volumes by age 19:				
Flexibility/mobility practice over 673.1 hours	2/12 (16.7%)	8/11 (72.7%)	6.67 (1.59 - 65.39)	High
Strength & Conditioning training over 581.41 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Weightlifting specific practice over 2123.28	3/12 (25%)	8/11 (72.7%)	4.5 (1.15 - 37.81)	High
Number of competitions over 18	5/12 (41.7%)	8/11 (72.7%)	2.33 (0.63 - 17.44)	-
Competition time over 159.54 hours	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-

Table 37. Odds ratio estimations for all logical attributes in the competitive milestones section

Attribute	Non-Elite	Elite	OR (95% CI)	Importance
By 12				
Domestic representation				
Highest domestic representation level by 12 under British Youth	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Age of first appearance at highest domestic level by 12 under 10.7	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Rank of first appearance at highest domestic level by 12 under 0.7	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Technical challenge of highest domestic competition by 12 under 5.7	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Psychological challenge of highest domestic competition by 12 under 5.7	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
By 15				
Domestic representation				
Highest domestic representation level by 15 at least British Youth	1/12 (8.3%)	6/11 (54.5%)	5.5 (1.17 - 70.07)	Moderate
Age of first appearance at highest domestic level by 15 under 14.75	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Rank of first appearance at highest domestic level by 15 over 1.07	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Technical challenge of highest domestic competition by 15 over 2.19	2/12 (16.7%)	6/11 (54.5%)	3.33 (0.83 - 29.63)	-
Psychological challenge of highest domestic competition by 15 under 5/10	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
International representation				
Highest international representation level by 15 over Continental Youth	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-

Age of first appearance at highest international level by 15 under 14.46	1/12 (8.3%)	5/11 (45.5%)	3.93 (0.84 - 50.17)	-
Rank of first appearance at highest international level by 15 3rd or better	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Technical challenge of highest international competition by 15 over 5/10	1/12 (8.3%)	4/11 (36.4%)	2.75 (0.58 - 36.24)	-
Psychological challenge of highest international competition by 15 over 5/10	1/12 (8.3%)	5/11 (45.5%)	3.93 (0.84 - 50.17)	-
Time spent injured by 15 over 0.26 months	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
By 19				
Domestic representation				
Highest domestic representation level by 19 was British Senior	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Age of first appearance at highest domestic level by 19 under 16.88	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Rank of first appearance at highest domestic level by 19 over 1.12	6/12 (50%)	3/11 (27.3%)	0.29 (0.08 - 2.15)	-
Technical challenge of highest domestic competition by 19 under 7/10	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Psychological challenge of highest domestic competition by 19 over 6/10	8/12 (66.7%)	5/11 (45.5%)	0.32 (0.09 - 2.24)	-
International representation				
Highest international representation level by 19 at least continental youth	0/12 (0%)	7/11 (63.6%)	16.8 (1.96 - 887.56)	High
Age of first appearance at highest international level by 19 over 16.01	7/12 (58.3%)	4/11 (36.4%)	0.31 (0.09 - 2.19)	-
Technical challenge of highest international competition by 19 over 6/10	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Psychological challenge of highest international competition by 19 over 6/10	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Time spent injured by 19 over 0.22 months	2/12 (16.7%)	6/11 (54.5%)	3.33 (0.83 - 29.63)	-

Table 38. Odds ratio estimations for all logical attributes in the practice activities in weightlifting section

Attribute	Non-Elite	Elite	OR (95% CI)	Importance
Deliberate Practice vs Play				
By 12				
Proportion of deliberate play at least 19%	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Proportion of deliberate practice at least 29%	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Volume of deliberate play more than 164.52 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Volume of deliberate practice more than 3.21 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
By 15				
Proportion of deliberate play at least 19%	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate

Proportion of deliberate practice at least 81%	5/12 (41.7%)	2/11 (18.2%)	0.23 (0.06 - 2.12)	-
Volume of deliberate play more than 56.3 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Volume of deliberate practice more than 492.63 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
By 19				
Proportion of deliberate play at least 5%	4/12 (33.3%)	6/11 (54.5%)	1.6 (0.45 - 11.18)	-
Proportion of deliberate practice at least 85%	5/12 (41.7%)	8/11 (72.7%)	2.33 (0.63 - 17.44)	-
Volume of deliberate play more than 299.96 hours	1/12 (8.3%)	2/11 (18.2%)	1.1 (0.22 - 18.19)	-
Volume of deliberate practice more than over 1952.99 hours	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Mental skills training (hours per week):				
By 12 over 4 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
By 15 over 563.96 hours	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
By 19 over 572.86 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Vicarious Experiences:				
By 12 over 27.21 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
By 15 over 80.82 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
By 19 over 73.75 hours	1/12 (8.3%)	8/11 (72.7%)	11 (2.26 - 153.3)	High
Information conveyed to the athlete:				
By 12				
Over 50% verbal information	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Over 29% demonstration information	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Under 1% video information	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
By 15				
Over 60% verbal information	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Over 34% demonstration information	1/12 (8.3%)	4/11 (36.4%)	2.75 (0.58 - 36.24)	-
Over 10% video information	4/12 (33.3%)	4/11 (36.4%)	0.8 (0.22 - 5.81)	-
By 19				
Over 50.83 verbal information	7/12 (58.3%)	3/11 (27.3%)	0.21 (0.06 - 1.59)	-
Over 26.96 demonstration information	2/12 (16.7%)	4/11 (36.4%)	1.67 (0.41 - 15.37)	-
Over 4% video information	4/12 (33.3%)	9/11 (81.8%)	4.8 (1.18 - 43.5)	High
Whole/Part Practice				
For the Snatch:				
By 12				
Proportion of snatch practice as parts over 69%	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Proportion of snatch practice as whole movement over 31%	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Number of separate movements practiced for part practice more than 3	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-

Volume of snatch part practice by 12 over 5.88 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Volume of snatch whole practice by 12 over 44.4 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
By 15				
Proportion of snatch practice as parts over 38%	5/12 (41.7%)	7/11 (63.6%)	1.63 (0.46 - 11.31)	-
Proportion of snatch practice as whole movement under 39%	1/12 (8.3%)	3/11 (27.3%)	1.83 (0.38 - 25.99)	-
Number of separate movements practiced for part practice more than 3 hours	5/12 (41.7%)	7/11 (63.6%)	1.63 (0.46 - 11.31)	-
Volume of snatch part practice by 15 over 125.3 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Volume of snatch whole practice by 15 over 96.8 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
By 19				
Proportion of snatch practice as parts over 35%	8/12 (66.7%)	10/11 (90.9%)	2.22 (0.47 - 29)	-
Proportion of snatch practice as whole movement over 56.49	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Number of separate movements practiced for part practice more than 4	7/12 (58.3%)	10/11 (90.9%)	3.12 (0.67 - 39.25)	-
Volume of snatch part practice by 19 over 684.7 hours	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Volume of snatch whole practice by 19 over 238.3 hours	1/12 (8.3%)	7/11 (63.6%)	7.7 (1.62 - 100.67)	High
For the Clean & Jerk:				
By 12				
Proportion of clean & jerk practice as parts over 54%	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Proportion of clean & jerk practice as whole movement over 28%	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Number of separate movements practiced for part practice at least 2	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Volume of clean & jerk part practice by 12 over 3.55 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Volume of clean & jerk whole practice by 12 over 66.54 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
By 15				
Proportion of clean & jerk practice as parts over 49%	5/12 (41.7%)	7/11 (63.6%)	1.63 (0.46 - 11.31)	-
Proportion of clean & jerk practice as whole movement over 24%	2/12 (16.7%)	6/11 (54.5%)	3.33 (0.83 - 29.63)	-
Number of separate movements practiced for part practice more than 5	4/12 (33.3%)	0/11 (0%)	0 (0 - 1.74)	-
Volume of clean & jerk part practice by 15 over 190.81 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Volume of clean & jerk whole practice by 15 over 147.6 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate

By 19				
Proportion of clean & jerk practice as parts under 78%	4/12 (33.3%)	10/11 (90.9%)	8 (1.69 - 103.46)	High
Proportion of clean & jerk practice as whole movement over 21%	4/12 (33.3%)	10/11 (90.9%)	8 (1.69 - 103.46)	High
Number of separate movements practiced for part practice at least 6	3/12 (25%)	7/11 (63.6%)	3.15 (0.83 - 24.6)	-
Volume of clean & jerk part practice by 19 over 764.7 hours	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Volume of clean & jerk part practice by 19 over 197.7 hours	1/12 (8.3%)	8/11 (72.7%)	11 (2.26 - 153.3)	High
Constant vs Varied Practice				
By 12				
Constant Practice proportion over 79%	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Varied Practice proportion over 9%	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Volume of practice with constant practice more than 185.96 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Volume of practice with varied practice more than 2.14 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
By 15				
Constant Practice proportion over 70%	3/12 (25%)	5/11 (45.5%)	1.61 (0.43 - 12.21)	-
Varied Practice proportion over 10%	2/12 (16.7%)	5/11 (45.5%)	2.38 (0.6 - 21.21)	-
Volume of practice with constant practice more than 333.42 hours	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Volume of practice with varied practice more than 200.93 hours	1/12 (8.3%)	2/11 (18.2%)	1.1 (0.22 - 18.19)	-
By 19				
Constant Practice proportion under 80%	4/12 (33.3%)	6/11 (54.5%)	1.6 (0.45 - 11.18)	-
Varied Practice proportion over 44%	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Volume of practice with constant practice more than 1586.2 hours	0/12 (0%)	6/11 (54.5%)	12 (1.4 - 621.53)	High
Volume of practice with varied practice more than 67.5 hours	1/12 (8.3%)	8/11 (72.7%)	11 (2.26 - 153.3)	High
Specificity of Practice				
Anxiety Specificity:				
By 12				
Proportion of overall practice under 1%	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Volume of Anxiety Specificity training over 0 hours	0/12 (0%)	0/11 (0%)	NA	NA
By 15				
Proportion of overall practice over 35%	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Anxiety Specificity Difficulty rating by 15 over 4/10	4/12 (33.3%)	6/11 (54.5%)	1.6 (0.45 - 11.18)	-
Volume of Anxiety Specificity training over 164 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
By 19				
Proportion of overall practice over 9%	4/12 (33.3%)	9/11 (81.8%)	4.8 (1.18 - 43.5)	High

Anxiety Specificity Difficulty rating by 19 over 4/10	4/12 (33.3%)	4/11 (36.4%)	0.8 (0.22 - 5.81)	-
Volume of Anxiety Specificity training over 342.14	0/12 (0%)	7/11 (63.6%)	16.8 (1.96 - 887.56)	High
Context Specificity:				
By 12				
Proportion of overall practice by 12 over 0%	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Context Specificity Difficulty rating by 12 at least 1/10	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Volume of context specificity training over 0 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
By 15				
Proportion of overall practice by 15 over 40%	3/12 (25%)	4/11 (36.4%)	1.12 (0.3 - 8.86)	-
Context Specificity Difficulty rating by 15 over 4/10	2/12 (16.7%)	3/11 (27.3%)	1.11 (0.27 - 11.09)	-
Volume of context specificity training over 16.09 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
By 19				
Proportion of overall practice by 19 over 8%	6/12 (50%)	10/11 (90.9%)	4.29 (0.92 - 53.14)	-
Context Specificity Difficulty rating by 19 at least 4/10	3/12 (25%)	8/11 (72.7%)	4.5 (1.15 - 37.81)	High
Volume of context specificity training over 348.57 hours	1/12 (8.3%)	8/11 (72.7%)	11 (2.26 - 153.3)	High
Focus of Attention				
By 12				
Proportion of practice with external focus of attention over 5%	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Proportion of practice with internal focus of attention over 45%	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Volume of practice with external focus of attention over 6.41 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
Volume of practice with internal focus of attention over 100.17 hours	0/12 (0%)	1/11 (9.1%)	1.09 (0.13 - 97.23)	-
By 15				
Proportion of practice with external focus of attention over 50%	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Proportion of practice with internal focus of attention over 43%	3/12 (25%)	1/11 (9.1%)	0.2 (0.05 - 3.18)	-
Volume of practice with external focus of attention over 270.81 hours	0/12 (0%)	5/11 (45.5%)	8.57 (1.01 - 445)	Moderate
Volume of practice with internal focus of attention over 100.17 hours	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
By 19				
Proportion of practice with external focus of attention over 9%	5/12 (41.7%)	9/11 (81.8%)	3.5 (0.88 - 30.58)	-

Proportion of practice with internal focus of attention over 24%	8/12 (66.7%)	10/11 (90.9%)	2.22 (0.47 - 29)	-
Volume of practice with external focus of attention over 290.13 hours	3/12 (25%)	7/11 (63.6%)	3.15 (0.83 - 24.6)	-
Volume of practice with internal focus of attention over 1587.56 hours	3/12 (25%)	5/11 (45.5%)	1.61 (0.43 - 12.21)	-
Source of feedback				
By 12				
Proportion of extrinsic feedback over 90%	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Proportion of intrinsic feedback under 5%	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
By 15				
Proportion of extrinsic feedback over 41%	4/12 (33.3%)	3/11 (27.3%)	0.53 (0.14 - 4.21)	-
Proportion of intrinsic feedback over 56%	1/12 (8.3%)	4/11 (36.4%)	2.75 (0.58 - 36.24)	-
By 19				
Proportion of extrinsic feedback over 40%	7/12 (58.3%)	3/11 (27.3%)	0.21 (0.06 - 1.59)	-
Proportion of intrinsic feedback over 51%	1/12 (8.3%)	7/11 (63.6%)	7.7 (1.62 - 100.67)	High
Prescriptive versus constraints coaching				
By 12				
Proportion of practice with constraints-based coaching over 0%	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Proportion of practice with prescriptive coaching over 69%	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
Volume of practice with constraints-based coaching over 3.23 hours	0/12 (0%)	2/11 (18.2%)	2.4 (0.28 - 153.74)	-
Volume of practice with prescriptive coaching over 18.2 hours	0/12 (0%)	3/11 (27.3%)	4 (0.47 - 225.93)	-
By 15				
Proportion of practice with constraints-based coaching at least 11%	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Proportion of practice with prescriptive coaching over 86%	5/12 (41.7%)	3/11 (27.3%)	0.39 (0.11 - 2.96)	-
Volume of practice with constraints-based coaching over 88.4 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Volume of practice with prescriptive coaching over 394.1 hours	3/12 (25%)	7/11 (63.6%)	3.15 (0.83 - 24.6)	-
By 19				
Proportion of practice with constraints-based coaching over 11%	2/12 (16.7%)	7/11 (63.6%)	4.67 (1.15 - 42.68)	High
Proportion of practice with prescriptive coaching over 69%	7/12 (58.3%)	8/11 (72.7%)	1.25 (0.34 - 9.38)	-
Volume of practice with constraints-based coaching over 434.3 hours	0/12 (0%)	4/11 (36.4%)	6 (0.7 - 319.52)	Moderate
Volume of practice with prescriptive coaching over 1687.6 hours	5/12 (41.7%)	7/11 (63.6%)	1.63 (0.46 - 11.31)	-

Supplementary Information: Chapter 4

Practice activities, Psychosocial and Physiological characteristics differentiating performance improvements in Youth and Junior Weightlifters: A longitudinal study

The aim of this supplementary document is to present:

1. The information sheet given to all participants prior to the study
2. The athlete development survey which includes all demographic and psychosocial questions
3. The results for the full analyses from each section

Bangor University, George Building, Bangor, Gwynedd LL57 2PZ
Weightlifting Wales, Canoflan Brailsford, Ffriddoedd Road, Gwynedd LL57 2EH

Participant Information Sheet

Study: Practice activities, Physiological and Psychosocial characteristics differentiating performance improvements in Junior and Youth Weightlifters.

Project Investigator

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This information sheet provides details about a study as part of the Talent Identification and Development project with Bangor University and Weightlifting Wales. We would like you to take part, but you do not have to. Taking part in the study will help researchers understand more information about your participation in weightlifting, which will help us to understand a little more about how we can help others like you develop in the future.

Invitation to take part in the study

You are invited to take part in a collaborative research investigation between Bangor University and Weightlifting Wales. Before you decide whether or not to take part, please make sure that you have understood the following:

1. Why we are doing this research
2. What we are asking you to do to help us

We will go over this information sheet together along with your parents/guardians if you are under the age of 18. Ask as many questions as you like!

What is Talent ID and Development?

In sport, Talent ID is a process that coaches and sport scientists use to identify and develop someone into potentially good weightlifters, and all-round athletes.

It usually includes testing how somebody performs a skill or set of tasks, or measuring how well their physical features match the needs of a sport.

Why are we doing our research?

Identifying potential can be difficult, this is because we are not always sure what the future looks like and how things could change with time.

With research, we can help coaches to use the right information to identify someone with potential. We can also help coaches to use this information to develop athletes of all abilities to become better at their sport.

Why have I been asked to take part?

As an athlete regularly participating in the sport of weightlifting, we hope that your participation will help us to develop a better understanding of talent ID and development in this sport.

Do I have to take part?

No, you do not have to take part in the study. It is completely voluntary. Feel free to discuss this with your coach or parents before agreeing to take part. You can also ask me any questions. If you choose to take part, you are free to leave the study at any time.

What will I be required to do if I agree to take part?

Our research will involve a number of youth and junior athletes from each performance Academy in Wales. We will ask you to complete a number of activities:

1. Power and Strength Tests (1RM Back Squat, Isometric Mid-Thigh Pull, Counter-Movement Jump, Single-Leg Counter Movement Jump, Grip Strength).
2. An Overhead Squat test.
3. Your Height, Weight, Body Composition (Bio-electrical impedance assessment, which entails the placement of two non-invasive electrodes on your hand and two on your foot. A completely painless current is then passed through these electrodes to measure body composition. Remember you are free to ask any questions to the researcher prior to consenting to do this) and Limb measurements (torso, full leg, thigh, lower leg, upper arm, forearm, second and fourth finger digit[1]). The measurements included in points 1, 2 and 3 above will be spread out throughout the day and take approximately 3.5 hours.
4. A series of Questionnaires about your Personality and Behaviour in Weightlifting Training and Competitions. Specifically, these relate to questions about: Conscientiousness, Obsessiveness, Ruthlessness & Selfishness, Perfectionism. This amounts to a total of 11 sections including a total of 110 questions (this will take about 30 mins to complete).
5. An interview with our researcher about your demographics, sporting history and practice activities in weightlifting. This asks about practice activities you engaged in, the proportion of time spent practicing per week, the intensity of practice, and the nature of practice activities. Specifically, we will be focusing on a typical week's practice that was specific to the technical development of the competitive lifts in weightlifting (this will take about 60 mins to complete).

On the day of the testing, your coaches will also be there to assist me. As it is important that you are sufficiently warmed up, the coach will take you through a normal weightlifting specific warm-up.

These activities will be repeated in eight months' time (i.e., ~mid December 2017) and then once more in a further eight months time from this (i.e., ~mid-

[1] All limb measurements will be taken whilst in normal training attire. Leg limb measurements will be taken from anterior superior iliac (i.e. hip) to the lateral condyles of the knee and ankle respectively. For arm measurements, landmarks will be from the acromio-clavicular joint (i.e. shoulder) to the lateral epicondyle (elbow) and lateral wrist condyle respectively. **At least two members of the research team will be present during all testing.**

August 2018). The information you give us during these activities is what we will use in our research. So, if you would like to take part, we will use your data to help us understand your development better and how we might be able to help.

What are the disadvantages to taking part?

As some of the tests will require you to use your maximum effort, it may cause you to feel temporarily uncomfortable if you have not completed a full warm up beforehand. Your coach and I will be with you on the day to make sure that you have completed a full warm up.

The testing will also require you to give up most of your morning and afternoon. We will normally aim to start at 9am and finish at 2.30pm. This can change, and if so, either myself or your coach will tell you with plenty of time. So, if you are able to attend, please try to make sure that it doesn't interrupt anything else you may have planned.

Furthermore, we will be filming your overhead squat in order for measurement purposes only, so that we can refer back to this if needed for an accurate measure. These videos will not be shared outside of the research team. Video records will be stored on a password protected computer.

Will my taking part in the study be kept confidential?

Yes, all personal information will be kept confidential and secure. All data will be recorded on a password protected computer and any hard copy files stored in a locked filing cabinet. Only the researchers involved in the study will have access to your personal information. We will analyse the measurements and your performance records at the University.

The results of this study will be most likely be published in a journal but it will not be possible to identify you from what is written.

Feedback on Conduct of Research

SSHES is always keen to hear the views of research participants about their experience. If you would like to feedback, please ask me to provide you with Form 6 – Participant Feedback Form – from the Ethics Guidelines Handbook. Completion of this form is optional. The completed form should be returned to Anthony Blanchfield, Chair, SSHES Ethics Committee, SSHES, Bangor University, Bangor LL57 2PZ. All information will be treated in a strictly confidential manner.

Who is organising or funding the research?

The research is organised by the Knowledge Economy Skills Scholarships (KESS), which is a pan-Wales higher level skills initiative led by Bangor University on behalf of the HE sector in Wales. It is part funded by the Welsh Government's European Social Fund (ESF) convergence programme for West Wales and the Valleys.

Who has reviewed the study?

The study has been reviewed by the SSHES institutional ethics committee and has been identified as not containing more than minimal risk to you as the participant.

What do it do if I have questions?

Please ask me if you have questions about any part of this study. Please do not sign the informed consent form if you have any unanswered questions or doubts.

Thank you very much for taking the time to read this information sheet.
If you choose to participate in this study you will be given a copy of the information sheet and a signed consent form to keep. Please sign and return this copy to either me or your coach before you begin taking part in the study.

Please note that the lead researcher directly involved in data collection for this project is DBS certified (Disclosure and Barring Service Form).

Ysgoloriaeth Sgiliau Economi Gwybodaeth (KESS) yn Gymru gyfan sgiliau lefel uwch yn fenter a arweinir gan Brifysgol Bangor ar ran y sector AU yng Nghymru. Fe'i cyllidir yn rhannol gan Gronfeydd Cymdeithasol Ewropeaidd (ESF) cydgyfeirio ar gyfer Gorllewin Cymru a'r Cymoedd.

Knowledge Economy Skills Scholarships (KESS) is a pan-Wales higher level skills initiative led by Bangor University on behalf of the HE sector in Wales. It is part funded by the Welsh Government's European Social Fund (ESF) convergence programme for West Wales and the Valleys.


kess
PRIFYSGOL
BANGOR
UNIVERSITY
WEIGHTLIFTING WALES
CODI PWYSAU CYMRU
Cronfa Gymdeithasol Ewrop
European Social Fund

2. A copy of the questionnaire given to each participant at baseline

Name:_____'s

Weightlifter Development Profile

Section 1 i)

My Full Name:			
Date of Birth: ____/____/_____			
What is the name of the town where you born?			
Parent Guardian			
Name: **Profession:** **Involvement in Sport: What experiences do they have in sport?** Include past and present experiences in competitive and recreational sport **What experience do they have with weightlifting?** Include playing and coaching experience.	**Father:**	**Mother:**	**Guardian:**
Siblings:			
Name: **Profession:** **Date of Birth:** **Involvement in Sport: What experiences do they have in sport?** Include past and present experiences in competitive and recreational sport	**Brother/Sister**	**Brother/Sister**	**Brother/Sister**

What experience do they have with weightlifting? Include playing and coaching experience.			

The Places I have lived:			
Please list the places you have lived for each year starting from when you were 6 years old:			
Age	**Name of Town**	**County or Post Code**	**Was this your family home? (Y/N)**
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

My Schooling:
Please list the places you went to school for each year starting from when you were 6 years old:

Age	Name of School	Was this a sport school? (Y/N)	Is this where you practiced most of your sport? (Y/N)
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Section 1 ii)

My Sport Involvement:

1. Please list all the sports you have played on the left hand column
2. Please tick the box for each at you have played each sport, starting when you were 6 years old.
3. Please put a circle around your 2 main sports, apart from weightlifting.

The sports I have played:	The ages I have played them (please tick):														
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Section 1 iii)

My Attitude to Training and Competition

You are about to complete a short 2-part questionnaire about your attitude to training and competition, and your personality. Please read each item carefully and think about how much you think this item describes you, then select the number that you think best describes you. It is important that you rate each item on how you they relate to you now, and not how you were previously or how you would like to be in the future. Please try to complete all items to the best of your knowledge. If you are unsure about an item, then select the number that relates to 'Not Sure'.

	Nothing like me			**I'm unsure**			**Very Like me**
1. It is important to me to perform as well as I possibly can.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
2. I want to perform as well as it is possible for me to perform.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
3. It is important for me to master all aspects of my performance.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
4. I worry that I may not perform as well as I possibly can.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
5. Sometimes I'm afraid that I may not perform as well as I'd like.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
6. I'm often concerned that I may not perform as well as I can perform.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

7. It is important to me to do well compared to others.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
8. It is important for me to perform better than others.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
9. My goal is to do better than most other performers.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
10. I just want to avoid performing worse than others.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
11. My goal is to avoid performing worse than everyone else.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
12. It is important for me to avoid being one of the worst performers in the group.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
13. I am concerned about the outcome of my performance or competition	**1**	**2**	**3**	**4**	**5**	**6**	**7**
14. I think a lot about coming first in a competition	**1**	**2**	**3**	**4**	**5**	**6**	**7**
15. I do not like it when others are better than me at something I am good at	**1**	**2**	**3**	**4**	**5**	**6**	**7**
16. I invest extra effort to win in small competitions.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
17. I like to receive feedback from my coach when I win	**1**	**2**	**3**	**4**	**5**	**6**	**7**
18. I find it difficult to accept losing	**1**	**2**	**3**	**4**	**5**	**6**	**7**
19. I normally focus on my opponents during a competition	**1**	**2**	**3**	**4**	**5**	**6**	**7**
20. Even in a training session, it is important for me to beat other people.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
21. I would not be happy about winning if I did not perform well	**1**	**2**	**3**	**4**	**5**	**6**	**7**
22. I would be satisfied with losing if I performed well	**1**	**2**	**3**	**4**	**5**	**6**	**7**
23. I lose motivation from a bad performance	**1**	**2**	**3**	**4**	**5**	**6**	**7**
24. I get frustrated when I am not performing correctly in training	**1**	**2**	**3**	**4**	**5**	**6**	**7**
25. I prefer to work on my weaknesses during training	**1**	**2**	**3**	**4**	**5**	**6**	**7**
26. I like to ask my coach for lots of tips for improvement	**1**	**2**	**3**	**4**	**5**	**6**	**7**
27. I am not interested in my opponents during a competition	**1**	**2**	**3**	**4**	**5**	**6**	**7**

28. I try to fit in as much training into my week as possible	**1**	**2**	**3**	**4**	**5**	**6**	**7**
29. I typically choose to train for longer than other people in my age group.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
30. I try to make my training sessions as productive as possible.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
31. My life revolves around my training.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
32. I complete extra training outside of my set training sessions.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
33. I would be willing to travel long distances to get to training.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
34. I normally do everything I can to get to training.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

35. I get frustrated when I miss a training session.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
36. I think about training a lot when I am not at training.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
37. No matter what is going on in my life, I still make it to training.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

38. I usually complete all the required training for a competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
39. I leave no stone unturned in preparation for a competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
40. I obsess about all the minor details in my preparation for a competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
41. Not being fully prepared for a competition scares me.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
42. It weighs on my mind when I have not prepared well for a competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

	Nothing like me			**I'm unsure**			**Very Like me**
43. I am drawn to the emotional intensity of important competitions.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
44. I thrive in the intense emotions of the competitive environment.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
45. I chose to engage with things that I am afraid of.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
46. I do not like being in the intense emotion of a competitive environment.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
47. I feel most alive when I am competing.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
48. I cannot control my emotions well in a competitive environment.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
49. I am not aware of my emotions during a competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
50. I am more emotionally expressive during competition than I am in everyday life.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
51. I am better at expressing myself physically than I am verbally.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

52. Select the Venn diagram that you feel best describes weightlifting as a part of your identity.

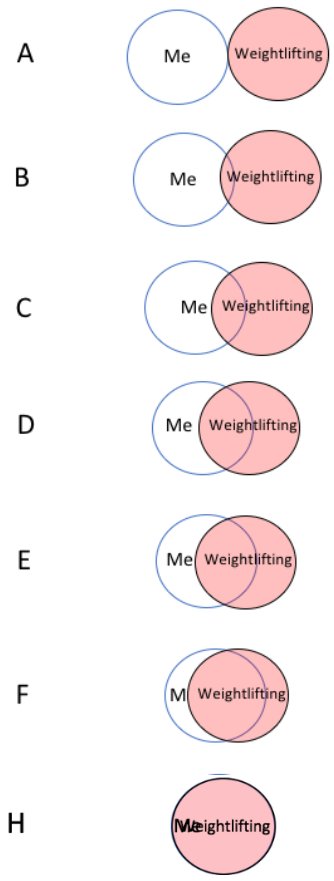

Diagram ___ best describes me.

53. I would describe weightlifting as being _____% part of my identity.

	Nothing like me			**I'm unsure**			**Very Like me**
54. For me, weightlifting is more important than spending time with friends.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
55. I am only interested in something if it is related to weightlifting.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
56. I prefer to spend my time at my weightlifting club than anywhere else.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
57. My life tends to revolve around weightlifting.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
58. I prefer training and competing more than other life interests.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

Section 2 ii)

My Personality

	Nothing like me			**I'm unsure**			**Very Like me**

59. I see myself as dependable and self-disciplined	**1**	**2**	**3**	**4**	**5**	**6**	**7**
60. I see myself as disorganised and careless	**1**	**2**	**3**	**4**	**5**	**6**	**7**
61. I see myself as extraverted, enthusiastic.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
62. I see myself as critical, quarrelsome.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
63. I see myself as anxious, easily upset.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
64. I see myself as open to new experiences, complex.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
65. I see myself as sympathetic, warm.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
66. I see myself as disorganised, careless.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
67. I see myself as calm, emotionally stable.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
68. I see myself as conventional, uncreative.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

69. When it comes to weightlifting, I can be selfish.	**I**	**2**	**3**	**4**	**5**	**6**	**7**
70. In weightlifting, I usually put myself before the interests of others.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
71. When it comes to weightlifting, I usually show my feelings of dissatisfaction when things are not to my liking.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
72. In weightlifting, if things are not to my liking, I am not afraid to say.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
73. I can be cunning and manipulative if I think it will help my weightlifting	**1**	**2**	**3**	**4**	**5**	**6**	**7**
74. I am willing to be disliked if it means being able to achieve my targets.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

75. I think I expect higher performance and greater results in my daily sport-training than most others.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
76. I have extremely high goals for myself in my sport.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
77. I set higher achievement goals than most athletes who play my sport.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
78. The fewer mistakes I make in competition, the more people will like me.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
79. If I do not do well all the time in competition, I feel that people will not respect me as an athlete.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
80. People will probably think less of me if I make mistakes in competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
81. My parents set very high standards for me in my sport.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
82. I feel like I am criticized by my parents for doing things less than perfectly in competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

83. In competition, I never feel like I can quite live up to my parents' standards.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
84. I feel like my coach criticizes me for doing things less than perfectly in competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
85. My coach sets very high standards for me in competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
86. Only outstanding performance in competition is good enough for my coach.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
87. I rarely feel that my training fully prepares me for competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
88. Prior to competition, I rarely feel satisfied with my training.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
89. I rarely feel that I have trained enough in preparation for a competition.	***1***	**2**	**3**	**4**	**5**	**6**	**7**
90. On the day of competition I have a routine that I try to follow.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
91. I follow pre-planned steps to prepare myself for competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
92. I follow a routine to get myself into a good mindset going into competition.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

93. The new things that I discover with weightlifting allow me to appreciate it even more.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
94. Weightlifting reflects the qualities I like about myself.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
95. Weightlifting is in harmony with the other activities in my life.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
96. For me Weightlifting is a passion, that I still manage to control.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
97. I cannot live without Weightlifting	**1**	**2**	**3**	**4**	**5**	**6**	**7**
98. Something inside me means that I can't help myself from doing Weightlifting.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
99. I have difficulty imagining my life without Weightlifting.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
100. I have almost an obsessive feeling for Weightlifting.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

101. The majority of my time is occupied by thoughts relating to weightlifting	**1**	**2**	**3**	**4**	**5**	**6**	**7**
102. Thoughts related to weightlifting interfere with my social life, schoolwork and other roles	**1**	**2**	**3**	**4**	**5**	**6**	**7**

103. My thoughts about weightlifting cause me to be distressed	**1**	**2**	**3**	**4**	**5**	**6**	**7**
104. I make conscious efforts to resist thinking about weightlifting.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
105. I have no control over my obsession with weightlifting.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
106. I spend the majority of my time performing weightlifting related behaviours.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
107. My behaviours related to weightlifting interfere with my social life, schoolwork and other roles.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
108. I would become anxious if I was prevented from weightlifting or weightlifting related behaviours.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
109. I make conscious efforts to resist my need for weightlifting related behaviours.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
110. I have no control over my need to obsession with weightlifting related behaviours.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

Table 39. Model coefficients for all linear models used to estimate normative data in chapter 4

Model	Term	Estimate (standard error)	t-statistic	P value	p <.05
Back squat to body mass ratio (women)	Intercept	-0.74 (0.5)	-1.48	0.15	
	Age	0.13 (0.03)	4.05	0	*
Back squat to body mass ratio (men)	Intercept	-1.55 (0.58)	-2.65	0.01	*
	Age	0.2 (0.04)	5.21	0	*
Front squat to body mass ratio (women)	Intercept	-0.68 (0.52)	-1.3	0.21	
	Age	0.11 (0.03)	3.36	0	*
Front squat to body mass ratio (men)	Intercept	-1.15 (0.47)	-2.43	0.02	*
	Age	0.16 (0.03)	5.01	0	*
Countermovement jump height (women)	Intercept	2.31 (12.56)	0.18	0.86	
	Age	2.53 (0.8)	3.18	0	*
Countermovement jump height (men)	Intercept	-27.76 (10.27)	-2.7	0.01	*
	Age	5 (0.68)	7.3	0	*
Countermovement jump peak power estimate (women)	Intercept	-351.41 (637.88)	-0.55	0.59	
	Age	202.74 (40.48)	5.01	0	*
Countermovement jump peak power estimate (men)	Intercept	-3669.81 (1037.57)	-3.54	0	*
	Age	455.22 (68.68)	6.63	0	*
Standing broad jump distance (women)	Intercept	96.14 (44.5)	2.16	0.04	*
	Age	4.9 (2.82)	1.74	0.1	
Standing broad jump distance (men)	Intercept	-6.02 (37.57)	-0.16	0.87	
	Age	13.73 (2.51)	5.48	0	*
Tibia length (women)	Intercept	39.18 (6.24)	6.28	0	*
	Age	-0.05 (0.39)	-0.13	0.9	
Tibia length (men)	Intercept	32.52 (4.51)	7.21	0	*
	Age	0.52 (0.3)	1.76	0.09	
Torso to height ratio (men)	Intercept	0.45 (0.05)	10.07	0	*
	Age	0 (0)	1.36	0.18	

Table 40. Logical conditions and Odds ratios for each demographics and familial sport participation attribute.

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Homeplace throughout development:				
Population of longest residing homeplace between 6 to 12 years over 11,369	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Population of longest residing homeplace between 13 to 15 years over 11,453	6/23 (26.1%)	4/6 (66.7%)	3.24 (0.81 - 29)	-
Population of homeplace at T1 over 16,959	3/23 (13%)	0/6 (0%)	0 (0.02 - 9.92)	-
Density of longest residing homeplace between 6 to 12 years over 767 pop/km^2	15/23 (65.2%)	6/6 (100%)	3 (0.36 - 142.56)	-
Density of longest residing homeplace between 13 to 15 years over 1,952 pop/km^2	2/23 (8.7%)	2/6 (33.3%)	2.8 (0.63 - 36.24)	-
Density of Homeplace Community at T1 over 2,344 pop/km^2	2/23 (8.7%)	2/6 (33.3%)	2.8 (0.63 - 36.24)	-
Relocated at least once throughout formative years	6/23 (26.1%)	1/6 (16.7%)	0.4 (0.1 - 5.52)	-
Familial sport participation				
Father involved in sport	15/23 (65.2%)	5/6 (83.3%)	1.25 (0.27 - 14.71)	-
Father experience in weightlifting	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Mother involved in sport	11/23 (47.8%)	3/6 (50%)	0.75 (0.2 - 5.86)	-
Mother experience in weightlifting	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Same sex sibling	7/23 (30.4%)	3/6 (50%)	1.5 (0.4 - 12.22)	-
Same sex older sibling	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
Same Sex Sibling experience in weightlifting	3/23 (13%)	0/6 (0%)	0 (0.02 - 9.92)	-
Schooling				
School main place for sport participation between 6 and 12 years	1/23 (4.3%)	4/6 (66.7%)	14.67 (2.81 - 259.57)	High
School main place for sport participation between ages 13 and 15	10/23 (43.5%)	3/6 (50%)	0.89 (0.24 - 6.95)	-
Distance from school to weightlifting club at T1 more than 15 km	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Relative Age				-
Month of birth over 1	23/23 (100%)	5/6 (83.3%)	0 (0 - 2.19)	-
Calendar Birth Quarter over 1	16/23 (69.6%)	5/6 (83.3%)	1.03 (0.23 - 12.33)	-
School Birth Quarter over 3	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
Relative age to nearest aged sibling less than 2,017 days	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-

Table 41. Logical conditions and Odds ratios for each physiology and anthropometrics attribute.

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Anthropometrics				
By T1:				
Height more than 0.03cm below norm	11/23 (47.8%)	4/6 (66.7%)	1.33 (0.34 - 11.16)	-
Body Mass more than 1.48kg above norm	10/23 (43.5%)	2/6 (33.3%)	0.47 (0.12 - 4.08)	-
BMI more than 2.76kg/m^2 above norm	5/23 (21.7%)	1/6 (16.7%)	0.5 (0.12 - 7.06)	-
By T2:				
Height more than 0.27cm above norm	11/23 (47.8%)	3/6 (50%)	0.75 (0.2 - 5.86)	-
Body Mass more than 0.95kg above norm	10/23 (43.5%)	2/6 (33.3%)	0.47 (0.12 - 4.08)	-
BMI more than 0.44kg/m^2 above norm	10/23 (43.5%)	2/6 (33.3%)	0.47 (0.12 - 4.08)	-
Between T1 and T2:				
Difference in Height between T1 and T2 more than 1.5cm above norm	2/23 (8.7%)	4/6 (66.7%)	9.33 (2.04 - 117.42)	High
Difference in Body Mass between T1 and T2 more than 0.6kg below norm	9/23 (39.1%)	4/6 (66.7%)	1.87 (0.48 - 15.8)	-
Difference in BMI between T1 and T2 more than 2.09kg/m^2 below norm	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Body Segments:				
By T1:				
Upper arm length more than 0.21cm above norm	7/23 (30.4%)	2/6 (33.3%)	0.8 (0.21 - 7.18)	-
Forearm length more than 0.01cm above norm	7/23 (30.4%)	4/6 (66.7%)	2.67 (0.67 - 23.26)	-
Hand length more than 3.08cm below norm	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Total arm length more than 1.63cm above norm	6/23 (26.1%)	4/6 (66.7%)	3.24 (0.81 - 29)	-
Torso length more than 5.22cm above norm	3/23 (13%)	1/6 (16.7%)	0.83 (0.19 - 13.47)	-
Leg length more than 4.93cm above norm	3/23 (13%)	2/6 (33.3%)	2 (0.48 - 22.13)	-
Thigh length more than 1.54cm above norm	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
Tibia length more than 3.79cm above norm	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Upper arm to height ratio below norm	14/23 (60.9%)	4/6 (66.7%)	0.8 (0.21 - 6.78)	-
Forearm to height ratio more than 0.01 below norm	6/23 (26.1%)	0/6 (0%)	0 (0.01 - 4.22)	-
Hand to height ratio below norm	8/23 (34.8%)	3/6 (50%)	1.25 (0.33 - 10)	-
Total Arm to height ratio above norm	7/23 (30.4%)	6/6 (100%)	12 (1.42 - 576.26)	High
Torso to height ratio more than 0.07 below norm	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Leg to height ratio more than 0.04 below norm	2/23 (8.7%)	0/6 (0%)	0 (0.03 - 15.6)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Thigh to height ratio more than 0.03 below norm	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Tibia to height ratio more than 0.01 below norm	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
By T2:				
Upper arm length more than 0.29cm above norm	8/23 (34.8%)	4/6 (66.7%)	2.22 (0.57 - 19.04)	-
Forearm length more than 0.32cm above norm	12/23 (52.2%)	4/6 (66.7%)	1.13 (0.29 - 9.45)	-
Hand length more than 0.04cm below norm	9/23 (39.1%)	4/6 (66.7%)	1.87 (0.48 - 15.8)	-
Total Arm length more than 0.9cm above norm	11/23 (47.8%)	5/6 (83.3%)	2.5 (0.55 - 28.72)	-
Torso length more than 2.51cm above norm	5/23 (21.7%)	3/6 (50%)	2.25 (0.58 - 19.57)	-
Leg length more than 7.32cm below norm	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Thigh length more than 1.34cm above norm	5/23 (21.7%)	3/6 (50%)	2.25 (0.58 - 19.57)	-
Tibia length more than 3.61cm below norm	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Upper arm length to height ratio below norm	10/23 (43.5%)	2/6 (33.3%)	0.47 (0.12 - 4.08)	-
Forearm to height ratio below norm	10/23 (43.5%)	1/6 (16.7%)	0.2 (0.05 - 2.53)	-
Hand to height ratio below norm	11/23 (47.8%)	3/6 (50%)	0.75 (0.2 - 5.86)	-
Total arm to height ratio more than 0.01 below norm	2/23 (8.7%)	0/6 (0%)	0 (0.03 - 15.6)	-
Torso to height ratio more than 0.07 below norm	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Leg to height ratio more than 0.03 below norm	2/23 (8.7%)	1/6 (16.7%)	1.17 (0.25 - 21.82)	-
Thigh to height ratio more than 0.02 below norm	3/23 (13%)	2/6 (33.3%)	2 (0.48 - 22.13)	-
Tibia to height ratio more than 0.01 below norm	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
Between T1 and T2:				
Difference in upper arm length between T1 and T2 more than 0.03cm above norm	9/23 (39.1%)	4/6 (66.7%)	1.87 (0.48 - 15.8)	-
Difference in forearm length between T1 and T2 more than 0.09cm above norm	11/23 (47.8%)	5/6 (83.3%)	2.5 (0.55 - 28.72)	-
Difference in hand length between T1 and T2 above norm	13/23 (56.5%)	5/6 (83.3%)	1.79 (0.39 - 20.6)	-
Difference in total arm length between T1 and T2 more than 2.95cm below norm	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Difference in torso length between T1 and T2 more than 1.54cm above norm	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Difference in total leg length between T1 and T2 more than 0.35cm above norm	5/23 (21.7%)	4/6 (66.7%)	4 (0.99 - 37.2)	-
Difference in thigh length between T1 and T2 more than 0.02cm above norm	7/23 (30.4%)	4/6 (66.7%)	2.67 (0.67 - 23.26)	-
Difference in tibia length between T1 and T2 more than 0.16cm above norm	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Difference in upper arm to height ratio between T1 and T2 more than 0.01cm below norm	5/23 (21.7%)	2/6 (33.3%)	1.2 (0.3 - 11.48)	-
Difference in forearm to height ratio between T1 and T2 more than 0.01cm below norm	4/23 (17.4%)	1/6 (16.7%)	0.63 (0.15 - 9.42)	-
Difference in hand to height ratio between T1 and T2 below norm	8/23 (34.8%)	2/6 (33.3%)	0.67 (0.17 - 5.88)	-
Difference in total arm to height ratio between T1 and T2 more than 0.03cm below norm	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Difference in torso to height ratio between T1 and T2 more than 0.01cm below norm	3/23 (13%)	0/6 (0%)	0 (0.02 - 9.92)	-
Difference in total leg to height ratio between T1 and T2 below norm	9/23 (39.1%)	4/6 (66.7%)	1.87 (0.48 - 15.8)	-
Difference in thigh to height ratio between T1 and T2 below norm	12/23 (52.2%)	5/6 (83.3%)	2.12 (0.47 - 24.31)	-
Difference in tibia to height ratio between T1 and T2 below norm	11/23 (47.8%)	5/6 (83.3%)	2.5 (0.55 - 28.72)	-
Digit Ratio				
By T1:				
R Hand Digit Length 2D:4D more than 0.09 below norm	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
L Hand Digit Length 2D:4D more than 0.05 below norm	3/23 (13%)	0/6 (0%)	0 (0.02 - 9.92)	-
Body Composition:				
By T1:				
Percent body fat more than 2.69% above norm	9/23 (39.1%)	3/6 (50%)	1.05 (0.28 - 8.29)	-
Fat Weight more than 2.87kg above norm	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
Lean Weight more than 1.13kg above norm	10/23 (43.5%)	2/6 (33.3%)	0.47 (0.12 - 4.08)	-
Dry Lean Weight more than 0.28kg above norm	11/23 (47.8%)	3/6 (50%)	0.75 (0.2 - 5.86)	-
Percent water more than 0.13% above norm	11/23 (47.8%)	4/6 (66.7%)	1.33 (0.34 - 11.16)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Total Body Water more than 1.52 litres above norm	10/23 (43.5%)	0/6 (0%)	0 (0 - 1.96)	-
Water weight more than 2.31kg above norm	9/23 (39.1%)	0/6 (0%)	0 (0.01 - 2.34)	-
By T2:				
Percent Body Fat more than 9.68% below norm	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Fat Weight more than 2.02kg above norm	5/23 (21.7%)	2/6 (33.3%)	1.2 (0.3 - 11.48)	-
Lean Weight more than 1.69kg below norm	9/23 (39.1%)	3/6 (50%)	1.05 (0.28 - 8.29)	-
Dry Lean Weight more than 1.93kg above norm	10/23 (43.5%)	0/6 (0%)	0 (0 - 1.96)	-
Percent water more than 6.71 above norm	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Total Body Water more than 0.2 litres above norm	11/23 (47.8%)	4/6 (66.7%)	1.33 (0.34 - 11.16)	-
Water weight more than 7.53kg above norm	4/23 (17.4%)	1/6 (16.7%)	0.63 (0.15 - 9.42)	-
Between T1 and T2:				
Difference in percent body fat between T1 and T2 more than 0.03 below norm	9/23 (39.1%)	3/6 (50%)	1.05 (0.28 - 8.29)	-
Difference in Fat Weight between T1 and T2 more than 3.48kg below norm	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Difference in Lean Weight between T1 and T2 more than 0.41kg above norm	8/23 (34.8%)	4/6 (66.7%)	2.22 (0.57 - 19.04)	-
Difference in Dry Lean Weight between T1 and T2 more than 0.4kg above norm	6/23 (26.1%)	2/6 (33.3%)	0.97 (0.25 - 8.95)	-
Difference in percent water between T1 and T2 more than 0.39 above norm	8/23 (34.8%)	3/6 (50%)	1.25 (0.33 - 10)	-
Difference in Total Body Water between T1 and T2 more than 0.33 litres above norm	6/23 (26.1%)	3/6 (50%)	1.82 (0.48 - 15.24)	-
Difference in water weight between T1 and T2 more than 1.75kg above norm	4/23 (17.4%)	3/6 (50%)	2.85 (0.72 - 26.26)	-
Stretch shortening cycle utilization:				
By T1:				
Sayers estimate for countermovement jump peak power more than 1027.66W above norm	3/23 (13%)	1/6 (16.7%)	0.83 (0.19 - 13.47)	-
Duncan estimate for countermovement jump peak power more than 225.28W above norm	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Maximum countermovement jump height more than 1.43cm above norm	7/23 (30.4%)	5/6 (83.3%)	5 (1.09 - 59.67)	-
Maximum squat jump height more than 0.22cm above norm	12/23 (52.2%)	4/6 (66.7%)	1.13 (0.29 - 9.45)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Maximum standing broad jump distance more than 11.08cm above norm	4/23 (17.4%)	4/6 (66.7%)	5.07 (1.22 - 49.85)	High
By T2:				
Sayers estimate for countermovement jump peak power more than 317.21W above norm	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Duncan estimate for countermovement jump peak power more than 232.77W above norm	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Maximum countermovement jump height more than 1.48cm above norm	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Maximum squat jump height more than 12.72cm above norm	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	High
Maximum standing broad jump distance more than 13.1cm above norm	8/23 (34.8%)	5/6 (83.3%)	4.17 (0.91 - 48.9)	-
Between T1 and T2:				
Difference in Sayers estimate for countermovement jump peak power between T1 and T2 more than 102.33W above norm	6/23 (26.1%)	3/6 (50%)	1.82 (0.48 - 15.24)	-
Difference in Duncan estimate for countermovement jump peak power between T1 and T2 more than 112.02W above norm	6/23 (26.1%)	2/6 (33.3%)	0.97 (0.25 - 8.95)	-
Difference in maximum countermovement jump height between T1 and T2 more than 4.63cm above norm	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
Difference in maximum squat jump height between T1 and T2 more than 0.09cm above norm	10/23 (43.5%)	4/6 (66.7%)	1.58 (0.4 - 13.23)	-
Difference in maximum standing broad jump distance between T1 and T2 more than 2.85cm below norm	9/23 (39.1%)	4/6 (66.7%)	1.87 (0.48 - 15.8)	-
Skeletal muscle strength:				
By T1:				
Maximum grip strength more than 10.53kg above norm	4/23 (17.4%)	1/6 (16.7%)	0.63 (0.15 - 9.42)	-
Maximum grip strength asymmetry more than 4.7kg above norm	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Back Squat to body mass ratio more than 0.67 above norm	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Front Squat to body mass ratio more than 0.03 above norm	8/23 (34.8%)	6/6 (100%)	10 (1.19 - 474.06)	High
By T2:				
Maximum grip strength more than 0.01kg above norm	9/23 (39.1%)	3/6 (50%)	1.05 (0.28 - 8.29)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Maximum grip strength asymmetry more than 5.22kg above norm	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Back Squat body mass ratio more than 1.02 above norm	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Front Squat body mass ratio more than 0.48 above norm	2/23 (8.7%)	3/6 (50%)	5.25 (1.19 - 62.13)	Moderate
Between T1 and T2:				
Difference in maximum grip strength between T1 and T2 more than 0.77kg above norm	11/23 (47.8%)	4/6 (66.7%)	1.33 (0.34 - 11.16)	-
Difference in Maximum grip strength asymmetry between T1 and T2 more than 0.55kg above norm	6/23 (26.1%)	3/6 (50%)	1.82 (0.48 - 15.24)	-
Difference in back squat to body mass ratio between T1 and T2 more than 0.01 above norm	12/23 (52.2%)	0/6 (0%)	0 (0 - 1.4)	Low
Difference in Front Squat body mass ratio between T1 and T2 more than 0.01 below norm	10/23 (43.5%)	5/6 (83.3%)	2.95 (0.65 - 34.05)	-
Mobility/Trunk Stability:				
By T1:				
OHS ankle angle more than 42.45 degrees	19/23 (82.6%)	5/6 (83.3%)	0.5 (0.11 - 6.75)	-
OHS thigh less than -5.73 degrees	14/23 (60.9%)	6/6 (100%)	3.6 (0.43 - 169.46)	-
OHS torso more than 66.71 degrees	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
OHS knee angle more than 22.59 degrees	22/23 (95.7%)	6/6 (100%)	0.26 (0.03 - 23.91)	-
OHS hip angle more than 42.17 degrees	19/23 (82.6%)	5/6 (83.3%)	0.5 (0.11 - 6.75)	-
OHS torso relative to ankle less than -7.39 degrees	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
By T2:				
OHS ankle more than 34.52 degrees	22/23 (95.7%)	6/6 (100%)	0.26 (0.03 - 23.91)	-
OHS thigh less than -14.91 degrees	7/23 (30.4%)	5/6 (83.3%)	5 (1.09 - 59.67)	-
OHS torso more than 60.39 degrees	7/23 (30.4%)	4/6 (66.7%)	2.67 (0.67 - 23.26)	-
OHS knee angle at more than 20.45 degrees	20/23 (87%)	6/6 (100%)	0.86 (0.1 - 48.86)	-
OHS hip angle at more than 41.52 degrees	17/23 (73.9%)	5/6 (83.3%)	0.83 (0.18 - 10.24)	-
OHS torso relative to ankle more than 13.07 degrees	5/23 (21.7%)	4/6 (66.7%)	4 (0.99 - 37.2)	-
Between T1 and T2:				
Difference in OHS ankle angle between T1 and T2 more than 0.26 degrees	10/23 (43.5%)	3/6 (50%)	0.89 (0.24 - 6.95)	-
Difference in OHS thigh angle between T1 and T2 more than 0.13 degrees	8/23 (34.8%)	2/6 (33.3%)	0.67 (0.17 - 5.88)	-
Difference in OHS torso angle between T1 and T2 more than 4.36 degrees	6/23 (26.1%)	2/6 (33.3%)	0.97 (0.25 - 8.95)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Difference in OHS knee angle between T1 and T2 more than 0.13 degrees	9/23 (39.1%)	1/6 (16.7%)	0.23 (0.06 - 3.02)	-
Difference in OHS hip angle between T1 and T2 more than 0.02 degrees	9/23 (39.1%)	2/6 (33.3%)	0.56 (0.15 - 4.88)	-
Difference in OHS torso to ankle angle between T1 and T2 more than 2.63 degrees	6/23 (26.1%)	2/6 (33.3%)	0.97 (0.25 - 8.95)	-

Table 42. Logical conditions and Odds ratios for each psychosocial attribute.

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Athlete behaviours and attitudes towards training and competition				
Achievement motivation				
Mastery Approach over 6.68	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Mastery Avoidance over 3.56	21/23 (91.3%)	2/6 (33.3%)	0.04 (0.01 - 0.49)	High
Performance Approach over 5.39	4/23 (17.4%)	4/6 (66.7%)	5.07 (1.22 - 49.85)	High
Performance Avoidance over 2.97	18/23 (78.3%)	5/6 (83.3%)	0.66 (0.14 - 8.39)	-
Athlete behaviours and attitudes				
Commitment to training over 4.7	10/23 (43.5%)	6/6 (100%)	7.09 (0.84 - 331.5)	High
Total preparation for competition over 5.15	6/23 (26.1%)	3/6 (50%)	1.82 (0.48 - 15.24)	
Counterphobic attitude over 4.24	8/23 (34.8%)	6/6 (100%)	10 (1.19 - 474.06)	High
Relative importance of sport over 3.55	10/23 (43.5%)	6/6 (100%)	7.09 (0.84 - 331.5)	High
Harmonious Passion over 5.72	2/23 (8.7%)	5/6 (83.3%)	17.5 (3.39 - 293.37)	High
Obsessive Passion over 4.63	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Athlete personality				
Conscientiousness over 5.81	5/23 (21.7%)	5/6 (83.3%)	7.5 (1.6 - 94.94)	High
Openness to Experience over 6.59	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Agreeableness over 2.33	22/23 (95.7%)	6/6 (100%)	0.26 (0.03 - 23.91)	-
Extraversion over 5.21	9/23 (39.1%)	6/6 (100%)	8.4 (1 - 394.78)	High
Emotional Stability over 4.49	15/23 (65.2%)	6/6 (100%)	3 (0.36 - 142.56)	-
Ruthlessness and Selfishness over 3.85	7/23 (30.4%)	5/6 (83.3%)	5 (1.09 - 59.67)	-
Perfectionism:				
P1: Perfectionist Strivings over 5.36	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
P2: Concern over mistakes over 1.09	21/23 (91.3%)	4/6 (66.7%)	0.12 (0.03 - 1.59)	-
P3: Perceived parental pressure over 3.37	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
P4: Perceived coach pressure over 2.71	12/23 (52.2%)	5/6 (83.3%)	2.12 (0.47 - 24.31)	-
P5: Doubts about actions over 2.35	22/23 (95.7%)	0/6 (0%)	0 (0 - 0.14)	High
P6: Organization over 5.61	2/23 (8.7%)	5/6 (83.3%)	17.5 (3.39 - 293.37)	High

Table 43. Logical conditions and Odds ratios for each sport participation history and weightlifting specific involvement attribute.

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Sport participation throughout development				
Number of sports sampled:				
Sampled at least 1 sport at age 6	13/23 (56.5%)	4/6 (66.7%)	0.95 (0.24 - 8.01)	-
Sampled at least 1 sport at age 7	14/23 (60.9%)	5/6 (83.3%)	1.5 (0.33 - 17.44)	-
Sampled at least 1 sport at age 8	16/23 (69.6%)	5/6 (83.3%)	1.03 (0.23 - 12.33)	-
Sampled at least 1 sport at age 9	17/23 (73.9%)	5/6 (83.3%)	0.83 (0.18 - 10.24)	-
Sampled at least 1 sport at age 10	20/23 (87%)	6/6 (100%)	0.86 (0.1 - 48.86)	-
Sampled at least 1 sport at age 11	21/23 (91.3%)	6/6 (100%)	0.55 (0.06 - 35.65)	-
Sampled at least 2 sports at age 12	10/23 (43.5%)	1/6 (16.7%)	0.2 (0.05 - 2.53)	-
Sampled at least 1 sport at age 13	22/23 (95.7%)	4/6 (66.7%)	0.06 (0.01 - 1.15)	-
Sampled at least 4 sports at age 14	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Sampled at least 1 sport at age 15	14/23 (60.9%)	3/6 (50%)	0.45 (0.12 - 3.56)	-
Sampled more than 2 sports between 6-12 years	7/23 (30.4%)	2/6 (33.3%)	0.8 (0.21 - 7.18)	-
Sampled more than 1 sport between 13-15 years	14/23 (60.9%)	4/6 (66.7%)	0.8 (0.21 - 6.78)	-
Years involved in each sport between 6 – 12 years:				
Athletics (no minimum)	5/23 (21.7%)	2/6 (33.3%)	1.2 (0.3 - 11.48)	-
Gymnastics for more than 3 years	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Motocross (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Rowing (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Jiu Jitsu (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Tennis (no minimum)	2/23 (8.7%)	0/6 (0%)	0 (0.03 - 15.6)	-
Karate (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Horse Riding (no minimum)	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Kickboxing (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Mountain Biking (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Badminton (no minimum)	2/23 (8.7%)	0/6 (0%)	0 (0.03 - 15.6)	-
Hockey (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Netball (no minimum)	2/23 (8.7%)	0/6 (0%)	0 (0.03 - 15.6)	-
Cricket for more than 1 year	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Football (no minimum)	10/23 (43.5%)	2/6 (33.3%)	0.47 (0.12 - 4.08)	-
Swimming (no minimum)	4/23 (17.4%)	0/6 (0%)	0 (0.02 - 7.06)	-
Basketball (no minimum)	2/23 (8.7%)	0/6 (0%)	0 (0.03 - 15.6)	-
Team Sports (no minimum)	16/23 (69.6%)	4/6 (66.7%)	0.55 (0.14 - 4.81)	-
Individual Sports for more than 2.5 years	8/23 (34.8%)	3/6 (50%)	1.25 (0.33 - 10)	
CGS Sports (no minimum)	13/23 (56.5%)	4/6 (66.7%)	0.95 (0.24 - 8.01)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Years involved in each sport between 13 – 15 years:				
CrossFit (no minimum)	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Athletics (no minimum)	4/23 (17.4%)	1/6 (16.7%)	0.63 (0.15 - 9.42)	-
Gymnastics (no minimum)	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Motocross (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Rounders (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Handball (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Badminton (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Hockey (no minimum)	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Netball (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Cricket (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Rugby for more than 2 years	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Football (no minimum)	4/23 (17.4%)	0/6 (0%)	0 (0.02 - 7.06)	-
Swimming (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Basketball (no minimum)	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Team Sports for more than 2 years	4/23 (17.4%)	1/6 (16.7%)	0.63 (0.15 - 9.42)	-
Individual Sport (no minimum)	23/23 (100%)	5/6 (83.3%)	0 (0 - 2.19)	-
CGS Sports (no minimum)	23/23 (100%)	5/6 (83.3%)	0 (0 - 2.19)	-
Weightlifting related involvement:				
Flexibility/mobility training (hours per week) at:				
Age 6 (no minimum)	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 7 (no minimum)	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 8 (no minimum)	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 9 (no minimum)	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 10 more than 0.15 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 11 more than 0.17 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 12 more than 0.88 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 13 more than 0.93 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 14 more than 1.66 hours	0/23 (0%)	4/6 (66.7%)	30.67 (3.45 - 2074.36)	High
Age 15 more than 1.85 hours	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
Strength & Conditioning Training (hours per week):				
Age 6 (no minimum)	0/23 (100%)	0/6 (100%)	NA	NA
Age 7 (no minimum)	0/23 (100%)	0/6 (100%)	NA	NA
Age 8 (no minimum)	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 9 more than 0.39 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 10 more than 0.49 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Age 11 more than 0.49 hours	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
Age 12 more than 0.46 hours	5/23 (21.7%)	3/6 (50%)	2.25 (0.58 - 19.57)	-
Age 13 more than 2.66 hours	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 14 more than 1.42 hours	4/23 (17.4%)	3/6 (50%)	2.85 (0.72 - 26.26)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Age 15 more than 2.13 hours	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Weightlifting specific practice (hours per week):				
Age 6 (no minimum)	0/23 (100%)	0/6 (100%)	NA	NA
Age 7 (no minimum)	0/23 (100%)	0/6 (100%)	NA	NA
Age 8 (no minimum)	0/23 (100%)	0/6 (100%)	NA	NA
Age 9 (no minimum)	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 10 more than 0.65 hours	3/23 (13%)	1/6 (16.7%)	0.83 (0.19 - 13.47)	-
Age 11 more than 0.96 hours	3/23 (13%)	2/6 (33.3%)	2 (0.48 - 22.13)	-
Age 12 more than 3 hours	2/23 (8.7%)	1/6 (16.7%)	1.17 (0.25 - 21.82)	-
Age 13 more than 4.48 hours	6/23 (26.1%)	1/6 (16.7%)	0.4 (0.1 - 5.52)	-
Age 14 more than 6.98 hours	3/23 (13%)	2/6 (33.3%)	2 (0.48 - 22.13)	-
Age 15 more than 6.89 hours	4/23 (17.4%)	3/6 (50%)	2.85 (0.72 - 26.26)	-
Total combined flex/mob, strength & conditioning, and weightlifting specific practice (hours per week):				
Age 6 (no minimum)	0/23 (100%)	0/6 (0%)	NA	NA
Age 7 (no minimum)	0/23 (100%)	0/6 (0%)	NA	NA
Age 8 (no minimum)	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 9 more than 1 hour	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 10 more than 1.2 hours	3/23 (13%)	1/6 (16.7%)	0.83 (0.19 - 13.47)	-
Age 11 more than 1.47 hours	5/23 (21.7%)	2/6 (33.3%)	1.2 (0.3 - 11.48)	-
Age 12 more than 4.03 hours	2/23 (8.7%)	2/6 (33.3%)	2.8 (0.63 - 36.24)	-
Age 13 more than 0.78 hours	17/23 (73.9%)	2/6 (33.3%)	0.06 (0.01 - 0.76)	Low
Age 14 more than 10.68 hours	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Age 15 more than 9.58 hours	3/23 (13%)	5/6 (83.3%)	12.5 (2.55 - 181.04)	High
Competitions per year:				
Age 6 at least 1 competition	0/23 (100%)	0/6 (0%)	NA	NA
Age 7 at least 1 competition	0/23 (100%)	0/6 (0%)	NA	NA
Age 8 at least 1 competition	0/23 (100%)	0/6 (0%)	NA	NA
Age 9 at least 1 competition	0/23 (100%)	0/6 (0%)	NA	NA
Age 10 more than 4 competitions	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 11 more than 4 competitions	2/23 (8.7%)	1/6 (16.7%)	1.17 (0.25 - 21.82)	-
Age 12 more than 4 competitions	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 13 at least 2 competitions	15/23 (65.2%)	1/6 (16.7%)	0.08 (0.02 - 1.09)	-
Age 14 at least 2 competitions	16/23 (69.6%)	3/6 (50%)	0.31 (0.08 - 2.52)	-
Age 15 more than 6 competitions	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Cumulative hours spent in competition:				
Age 6 (no minimum)	0/23 (100%)	0/6 (0%)	NA	NA
Age 7 (no minimum)	0/23 (100%)	0/6 (0%)	NA	NA
Age 8 (no minimum)	0/23 (0%)	0/6 (0%)	NA	NA
Age 9 (no minimum)	0/23 (0%)	0/6 (0%)	NA	NA

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Age 10 more than 8.26 hours	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 11 more than 10.09 hours	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 12 more than 12.03 hours	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 13 more than 12.48 hours	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 14 more than 19.29 hours	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Age 15 more than 21.44 hours	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Cumulative practice volumes by T1:				
Flexibility/mobility practice over 255.79 hours	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
Strength & Conditioning training over 936.24 hours	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
Weightlifting specific practice over 657.18 hours	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Number of competitions over 8	8/23 (34.8%)	6/6 (100%)	10 (1.19 - 474.06)	High
Competition time over 43.08 hours	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Cumulative practice volumes by T2:				
Flexibility/mobility practice over 195.3 hours	1/23 (4.3%)	4/6 (66.7%)	14.67 (2.81 - 259.57)	High
Strength & Conditioning training over 603.17 hours	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	High
Weightlifting specific practice over 1527.54 hours	2/23 (8.7%)	4/6 (66.7%)	9.33 (2.04 - 117.42)	High
Number of competitions over 10	8/23 (34.8%)	6/6 (100%)	10 (1.19 - 474.06)	High
Competition time over 53.49 hours	3/23 (13%)	5/6 (83.3%)	12.5 (2.55 - 181.04)	High
Cumulative practice volumes between T1 and T2:				
Flexibility/mobility practice over 29.18 hours	5/23 (21.7%)	6/6 (100%)	18 (2.11 - 904.9)	High
Strength & Conditioning training over 23.14 hours	12/23 (52.2%)	6/6 (100%)	5.08 (0.6 - 236.85)	-
Weightlifting specific practice over 392.28 hours	2/23 (8.7%)	3/6 (50%)	5.25 (1.19 - 62.13)	High
Number of competitions over 0	13/23 (56.5%)	5/6 (83.3%)	1.79 (0.39 - 20.6)	-
Competition time over 0	13/23 (56.5%)	5/6 (83.3%)	1.79 (0.39 - 20.6)	-

Table 7. Logical conditions and Odds ratios for each practice activities in weightlifting attribute.

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Deliberate Practice vs Play By T1:				
Proportion of deliberate play at least 5%	15/23 (65.2%)	5/6 (83.3%)	1.25 (0.27 - 14.71)	-
Proportion of deliberate practice at least 95%	8/23 (34.8%)	1/6 (16.7%)	0.28 (0.07 - 3.64)	-
Volume of deliberate play more than 313.8 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Volume of deliberate practice more than 1078.9 hours	3/23 (13%)	4/6 (66.7%)	6.67 (1.55 - 71.7)	Moderate
By T2:				
Proportion of deliberate play more than 40%	4/23 (17.4%)	0/6 (0%)	0 (0.02 - 7.06)	-
Proportion of deliberate practice more than 60%	19/23 (82.6%)	6/6 (100%)	1.2 (0.14 - 63.58)	-
Volume of deliberate play over 100 hours	14/23 (60.9%)	5/6 (83.3%)	1.5 (0.33 - 17.44)	-
Volume of deliberate practice more than 1426.51 hours	2/23 (8.7%)	4/6 (66.7%)	9.33 (2.04 - 117.42)	High
Between T1 and T2:				
Reduced deliberate play proportion by more than 5 percentage units	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
Increased deliberate practice proportion by more than 5 percentage units	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
Volume of deliberate play between T1 and T2 more than 100 hours	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Volume of deliberate practice between T1 and T2 more than 297.98 hours	2/23 (8.7%)	3/6 (50%)	5.25 (1.19 - 62.13)	Moderate
Mental skills training (hours per week):				
At T1 over 14.2 hours	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
At T2 over 15.7 hours	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Increase between T1 and T2 over 0.98 hours	4/23 (17.4%)	0/6 (0%)	0 (0.02 - 7.06)	
Vicarious Experiences (hours per week):				
By T1 over 4.1 hours	4/23 (17.4%)	4/6 (66.7%)	5.07 (1.22 - 49.85)	High
By T2 over 0.89 hours	13/23 (56.5%)	6/6 (100%)	4.29 (0.51 - 200.54)	-
Decrease between T1 and T2 more than 2.16 hours	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Information conveyed to the athlete:				
At T1:				
Over 40.49% verbal information	23/23 (100%)	4/6 (66.7%)	0 (0 - 0.94)	Moderate
Over 31.07% demonstration information	3/23 (13%)	5/6 (83.3%)	12.5 (2.55 - 181.04)	High
Over 20.03% video information	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	
At T2:				
Over 50.95% verbal information	23/23 (100%)	1/6 (16.7%)	0 (0 - 0.16)	Moderate
Over 29.69% demonstration information	19/23 (82.6%)	6/6 (100%)	1.2 (0.14 - 63.58)	
Over 18.08% video information	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	High
Between T1 and T2:				
Reduction in verbal information by more than 10 percentage units	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Reduction in demonstrations by more than 9.7 percentage units	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Increase in video information by more than 10.3 percentage unit	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
Whole/Part Practice				
For the Snatch:				
At T1:				
Proportion of snatch practice as parts over 61%	17/23 (73.9%)	3/6 (50%)	0.25 (0.07 - 2.1)	-
Proportion of snatch practice as whole movement over 39%	6/23 (26.1%)	3/6 (50%)	1.82 (0.48 - 15.24)	-
Number of separate movements practiced for part practice more than 4	16/23 (69.6%)	6/6 (100%)	2.47 (0.29 - 119.06)	-
Volume of snatch part practice by T1 over 247.8 hours	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Volume of snatch whole practice by T1 over 265.9 hours	0/23 (0%)	4/6 (66.7%)	30.67 (3.45 - 2074.36)	High
At T2:				
Proportion of snatch practice as parts of movement over 71%	6/23 (26.1%)	0/6 (0%)	0 (0.01 - 4.22)	-
Proportion of snatch practice as whole movement over 29%	17/23 (73.9%)	6/6 (100%)	2 (0.24 - 98.36)	-
Volume of snatch part practice by T2 over 313.2 hours	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Number of separate movements practiced for part practice more than 4	16/23 (69.6%)	6/6 (100%)	2.47 (0.29 - 119.06)	-
Volume of snatch whole practice by T2 more than 327.2 hours	0/23 (0%)	4/6 (66.7%)	30.67 (3.45 - 2074.36)	High
Between T1 and T2:				
Reduced the proportion of part practice for the snatch between T1 and T2 by at least 1%	2/23 (8.7%)	0/6 (0%)	0 (0.03 - 15.6)	-
Reduced the number of parts practiced for snatch by at least 1 part between T1 and T2	1/23 (4.3%)	0/6 (0%)	0 (0.04 - 31.84)	-
Increased snatch whole practice proportion between T1 and T2 by at least 1%	2/23 (8.7%)	0/6 (0%)	0 (0.03 - 15.6)	-
Volume of snatch part practice between T1 and T2 more than 50.5 hours	14/23 (60.9%)	5/6 (83.3%)	1.5 (0.33 - 17.44)	-
Volume of snatch whole practice between T1 and T2 more than 69.6	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	High
For the Clean & Jerk:				
At T1:				
Proportion of clean & jerk practice as parts over 49%	23/23 (100%)	4/6 (66.7%)	0 (0 - 0.94)	Moderate
Number of separate movements practiced for part practice at least 3	21/23 (91.3%)	5/6 (83.3%)	0.23 (0.05 - 3.97)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Proportion of clean & jerk practice as whole movement over 51%	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Volume of clean & jerk part practice by T1 more than 241.2 hours	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	Moderate
Volume of clean & jerk as whole practice more than 206.3 hours	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	Moderate
At T2:				
Proportion of clean & jerk practice as parts over 71%	15/23 (65.2%)	0/6 (0%)	0 (0 - 0.84)	Moderate
Number of separate movements practiced for part practice more than 5	6/23 (26.1%)	0/6 (0%)	0 (0.01 - 4.22)	-
Proportion of clean & jerk practice as whole movement over 29%	11/23 (47.8%)	6/6 (100%)	6 (0.71 - 279.83)	-
Volume of clean & jerk part practice more than 315 hours by T2	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Volume of clean & jerk as whole practice more than 132.3 hours by T2	4/23 (17.4%)	4/6 (66.7%)	5.07 (1.22 - 49.85)	High
Between T1 and T2:				
Increased the proportion of part practice for the clean & jerk between T1 and T2 by at least 10%	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Increased the number of parts practiced for clean & jerk by at least 1 part between T1 and T2	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Reduced the proportion of clean & jerk whole practice between T1 and T2 by at least 10%	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Volume of clean & jerk part practice more than 99 hours between T1 and T2	5/23 (21.7%)	4/6 (66.7%)	4 (0.99 - 37.2)	-
Volume of clean & jerk whole practice more than 50 hours practice between T1 and T2	2/23 (8.7%)	4/6 (66.7%)	9.33 (2.04 - 117.42)	High
Constant vs Varied Practice				
At T1:				
Constant Practice proportion over 86%	17/23 (73.9%)	1/6 (16.7%)	0.06 (0.01 - 0.76)	Moderate
Varied Practice proportion over 21%	3/23 (13%)	4/6 (66.7%)	6.67 (1.55 - 71.7)	High
Volume of practice with constant practice more than 1576.28 hours	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Volume of practice with varied practice more than 173.52 hours	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
At T2:				
Constant Practice proportion over 80%	18/23 (78.3%)	2/6 (33.3%)	0.11 (0.03 - 1.01)	-
Varied Practice proportion over 12%	6/23 (26.1%)	5/6 (83.3%)	6.07 (1.31 - 74.22)	Moderate
Volume of practice with constant practice more than 1020.11 hours	4/23 (17.4%)	2/6 (33.3%)	1.52 (0.38 - 15.39)	-
Volume of practice with varied practice more than 222.39 hours	1/23 (4.3%)	4/6 (66.7%)	14.67 (2.81 - 259.57)	Moderate

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Between T1 and T2:				
Decreased constant practice proportion between T1 and T2 by at least 1%	2/23 (8.7%)	0/6 (0%)	0 (0.03 - 15.6)	-
Increased varied practice proportion by at least 1%	2/23 (8.7%)	0/6 (0%)	0 (0.03 - 15.6)	-
Volume of constant practice between T1 and T2 more than 259.53 hours	5/23 (21.7%)	3/6 (50%)	2.25 (0.58 - 19.57)	-
Volume of varied practice between T1 and T2 more than 135.62 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Specificity of Practice				
Anxiety Specificity:				
By T1:				
Proportion of overall practice over 31.08%	1/23 (4.3%)	3/6 (50%)	8.25 (1.63 - 138.06)	Moderate
Volume of Anxiety Specificity training over 443.9 hours	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
Anxiety Specificity Difficulty rating by T1 over 6/10	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
By T2:				
Proportion of overall practice by T2 over 35.8	3/23 (13%)	3/6 (50%)	3.75 (0.91 - 37.83)	-
Volume of Anxiety Specificity t2 over 556.77	0/23 (0%)	3/6 (50%)	17.25 (1.98 - 1117.65)	High
Anxiety Specificity Difficulty rating by T2 over 4/10	14/23 (60.9%)	2/6 (33.3%)	0.24 (0.06 - 2.09)	-
Between T1 and T2:				
Increase in overall proportion of practice that is Anxiety Specific between T1 and T2 by at least 1%	5/23 (21.7%)	0/6 (0%)	0 (0.01 - 5.35)	-
Accumulated a volume of anxiety specificity practice by more than 112 hours between T1 and T2	1/23 (4.3%)	4/6 (66.7%)	14.67 (2.81 - 259.57)	High
Reduction in the rated difficulty of the anxiety specific training between T1 and T2 by at least 1 Likert scale point	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
Context Specificity:				
By T1:				
Proportion of overall practice by T1 over 36%	4/23 (17.4%)	3/6 (50%)	2.85 (0.72 - 26.26)	-
Volume of context specificity training over 162.06 hours	4/23 (17.4%)	4/6 (66.7%)	5.07 (1.22 - 49.85)	High
Context Specificity Difficulty rating by T2 over 6/10	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-
By T2:				
Proportion of overall practice by T2 over 36.48	5/23 (21.7%)	3/6 (50%)	2.25 (0.58 - 19.57)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Volume of context specificity training over 1071.64 hours by T2	2/23 (8.7%)	3/6 (50%)	5.25 (1.19 - 62.13)	High
Context Specificity Difficulty rating by T2 over 2/10	23/23 (100%)	4/6 (66.7%)	0 (0 - 0.94)	-
Between T1 and T2:				
Increase in overall proportion of practice that is context specific between T1 and T2 by at least 1%	5/23 (21.7%)	0/6 (0%)	0 (0.01 - 5.35)	-
Volume of context specificity practice more than 105 hours between T1 and T2	5/23 (21.7%)	4/6 (66.7%)	4 (0.99 - 37.2)	-
Reduction in the rated difficulty of the context specific training between T1 and T2 by more than 1 Likert scale point	2/23 (8.7%)	1/6 (16.7%)	1.17 (0.25 - 21.82)	-
Focus of Attention				
By T1:				
Proportion of practice with internal focus of attention over 41%	18/23 (78.3%)	3/6 (50%)	0.2 (0.05 - 1.73)	-
Proportion of practice with external focus of attention over 55%	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Volume of practice with internal focus of attention over 281.26 hours by T1	4/23 (17.4%)	5/6 (83.3%)	9.5 (1.99 - 126.68)	High
Volume of practice with external focus of attention over 346.04 hours by T1	2/23 (8.7%)	4/6 (66.7%)	9.33 (2.04 - 117.42)	High
By T2:				
Proportion of practice with internal focus of attention over 41%	18/23 (78.3%)	2/6 (33.3%)	0.11 (0.03 - 1.01)	-
Proportion of practice with external focus of attention over 55%	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Volume of practice with internal focus of attention over 479.55 hours by T2	5/23 (21.7%)	5/6 (83.3%)	7.5 (1.6 - 94.94)	High
Volume of practice with external focus of attention over 1100.94 hours	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	High
Between T1 and T2:				
Reduction in proportion of practice with internal focus of attention by more than 30%	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	-
Reduction in proportion of practice with external focus of attention by at least 1%	3/23 (13%)	0/6 (0%)	0 (0.02 - 9.92)	-
Accumulated a volume of practice with internal focus of attention of more than 138.94 hours between T1 and T2	7/23 (30.4%)	3/6 (50%)	1.5 (0.4 - 12.22)	-
Accumulated a volume of practice with external focus of attention of more than 184.97 hours between T1 and T2	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Source of feedback				

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
By T1:				
Proportion of intrinsic feedback over 21%	2/23 (8.7%)	5/6 (83.3%)	17.5 (3.39 - 293.37)	High
Proportion of extrinsic feedback over 79%	21/23 (91.3%)	1/6 (16.7%)	0.02 (0 - 0.3)	High
By T2:				
Proportion of intrinsic feedback over 25%	3/23 (13%)	5/6 (83.3%)	12.5 (2.55 - 181.04)	High
Proportion of extrinsic feedback over 75%	20/23 (87%)	1/6 (16.7%)	0.02 (0.01 - 0.39)	High
Between T1 and T2:				
Increased proportion of intrinsic feedback of more than 5 percentage units between T1 and T2	11/23 (47.8%)	2/6 (33.3%)	0.4 (0.11 - 3.44)	-
Reduced proportion of extrinsic feedback of more than 5 percentage units between T1 and T2	11/23 (47.8%)	2/6 (33.3%)	0.4 (0.11 - 3.44)	-
Prescriptive versus constraints coaching				
By T1:				
Proportion of practice with constraints-based coaching over 30%	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Proportion of practice with prescriptive coaching over 49%	22/23 (95.7%)	2/6 (33.3%)	0.02 (0 - 0.36)	High
Volume of practice with constraints-based coaching over 232.49 hours by T1	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Volume of practice with prescriptive coaching over 1710.24 hours by T1	0/23 (0%)	1/6 (16.7%)	3.83 (0.46 - 359.03)	
By T2:				
Proportion of practice with constraints-based coaching over 20%	3/23 (13%)	4/6 (66.7%)	6.67 (1.55 - 71.7)	High
Proportion of practice with prescriptive coaching over 40%	22/23 (95.7%)	2/6 (33.3%)	0.02 (0 - 0.36)	High
Volume of practice with constraints-based coaching over 366.24 hours by T2	0/23 (0%)	2/6 (33.3%)	9.2 (1.06 - 640.23)	Moderate
Volume of practice with prescriptive coaching over 111.54 hours by T2	22/23 (95.7%)	6/6 (100%)	0.26 (0.03 - 23.91)	-
Between T1 and T2:				
Increase in the proportion of practice with constraints-based coaching by more than 19% between T1 and T2	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Reduce the proportion of practice with prescriptive coaching by more than 39% between T1 and T2	1/23 (4.3%)	1/6 (16.7%)	1.83 (0.35 - 47.3)	-

Attribute	Non-Elite (FPR)	Elite (TPR)	OR (95% CI)	Importance
Accumulated a volume of practice with constraints-based coaching of more than 100.14 hours between T1 and T2	1/23 (4.3%)	2/6 (33.3%)	4.4 (0.87 - 80.11)	-
Accumulated a volume of practice with prescriptive coaching of more than 125.21 hours between T1 and T2	12/23 (52.2%)	3/6 (50%)	0.63 (0.17 - 4.96)	-