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‘Game Changers’: Discriminating Features within the Microstructure of Practice and Developmental Histories of Super-Elite Cricketers - a Pattern Recognition Approach

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‘Game Changers’

Discriminating Features within the Microstructure of Practice and Developmental Histories of Super-Elite Cricketers: A Pattern Recognition Approach

PRIFYSGOL BANGOR UNIVERSITY

Ph.D. Thesis

by

Benjamin David Jones

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.

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Dedication

This thesis is dedicated to my great friend, Llywelyn (Llew) Williams, who passed away on April 21st 2019. Llew was the friendliest of giants, and his death leaves an unfillable hole in the lives of all fortunate enough to have spent any length of time with him; I am extremely fortunate to have called him my friend, and will treasure the memories forever.

"Nid wy'n gofyn bywyd moethus,
Aur y byd na'I berlau mân:
Gofyn wyf am galon hapus,
Calon onest, calon lân.

Calon lân yn llawn daioni,
Tecach yw na'r lili dlos:
Dim ond calon lân all ganu
Canu'r dydd a chanu'r nos."

CONTENTS

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"Talent does not discriminate - opportunity does"

A significant milestone in my family history passed at the midpoint of the PhD; 100 years since Richard O'Carroll, my Great, Great Grandfather, made the ultimate sacrifice for his beloved Ireland, during the 1916 Easter Rising; Richard was from a poor working class family, and was the first in his family to learn to read and write, having received a limited education before joining his father and uncle as a bricklayer in Dublin. Richard maximised his potential within the constraints of limited opportunities available to him, becoming a founding member of the Labour party in Ireland, and mayor-elect for Dublin, at the time of his death. His life legacy is commemorated by the 'Richard O'Carroll Empowerment Education Bursary' now offered, to empower young people through education. Although a century apart, I hope to continue maximising the opportunities available to me, in his honour.

Thesis Abstract

This thesis advances understanding of expertise development by addressing notable methodological issues, to become the first in field to quantitatively measure the influence of the microstructure of practice in the development of expertise in a sample of truly elite (super-elite) sportsmen, using machine learning techniques. The research protocol provides a means of bridging the existing gap between expertise development theory and research, and its application for talent identification and development (Baker, Schorer & Wattie, 2018; Holt et al., 2018). The thesis contains six chapters, including three research papers.

Chapter 1 critically reviews the research on expertise development in sport to date and presents the rationale for the research programme, which aimed to overcome the theoretical and empirical limitations of this research, namely: (i) restricting investigation to comparisons of practice quantity; (ii) one-dimensional studies of individual expertise domains, disregarding the multifaceted nature of expertise; (iii) reliance on linear analysis techniques in identifying isolated precursors of expertise; (iv) assumptions of homogeneity within sports; and (v) inconsistent benchmarking measures for classifying expertise (Coutinho, Mesquita & Fonseca, 2016; Jones, Lawrence & Hardy, 2018; Schorer & Elferink-Gemser, 2013).

Chapter 2 presents two studies to determine whether the relative age effect (RAE) observed in youth sport, extends into 'super elite' performers (Cobley, Baker, Wattie & Mckenna, 2009). The findings provide new evidence of RAEs at the super-elite level, presenting both inter and intra-sport differences (Jones et al., 2018). The research developed and applied a set of stringent criteria to benchmark super-elite expertise, and considered inter and intra-sport differences, by assessing RAE prevalence across the disciplines/positions of cricket and rugby union separately. Potential explanations for the findings are explored, owing to the survival and evolution of the fittest concepts, which suggest that RAE is a contributing factor in the efficient turnover of performers who do excel in sport.

Chapter 3 applies non-linear machine learning (pattern recognition) analysis to a set of 93 developmental features (variables) obtained from a sample of sub-elite and elite cricket spin bowlers. The analysis produced a holistic predictive model consisting of 12 developmental features, from 93 measured, that discriminated between the elite and sub-elite groups, with very good accuracy (85%). The 12-feature model highlights elite spin bowlers' greater quantity of domain-specific practice. The external validity of this new multidimensional non-linear model is also tested. Qualitative data obtained was subsequently analysed to achieve a deeper understanding of the discriminating features. A working group of England and Wales Cricket Board (ECB) pathway coaches and practitioners were invited to scrutinise the interpretation of findings, producing recommendations for the wider game.

Chapter 4 examines the predictive power of the nature and microstructure of practice activity in a comparison of super-elite and elite cricket batsmen, domains of expertise development previously unexplored simultaneously. The findings identify psychologically challenging skill-based practice, relatively early in the development journey (age 16), as a catalyst for progression to super-elite expertise. The study modelled the development experiences of the super-elite and elite by adopting non-linear pattern recognition techniques, producing a holistic predictive model containing 18 features, from a possible 658, that discriminated between the super-elite and elite batsmen with excellent classification accuracy (96.3%). Evidence for the external validity of this model is presented.

The impact of the PhD, measured by its overall contribution to the ECB's talent pathway processes, is presented in Chapter 5. Chapter 6 contains a general discussion of the theoretical implications of the thesis' discriminating findings, and commonalities identified across the levels of expertise. Finally, the combined theoretical and applied value of the research protocol is further evidenced by its cross-sport application to research programmes recently commissioned by UK Sport and The Rugby Football Union.

Chapter 1

General Introduction

“You can't connect the dots looking forward; you can only connect them looking backwards. So you have to trust that the dots will somehow connect in your future.” – Steve Jobs

Setting the Scene

Current knowledge from expertise research suggests that expertise attainment is highly likely the end-result of an enormously complex interaction between genetic and developmental features[1] (for a review *see* Jonhston, Wattie, Schorer, & Baker, 2018; Baker & Cobley, 2013; Baker, Wattie, & Schorer, 2018). In a recent review, Rees et al. (2016) argue that differences in early experiences, preferences, opportunities, habits, training, and practice activities are the strongest determinants of mastery in the development of expertise, possessing varying importance at different stages of development. The conversion of ‘giftedness’ into ‘talent’ is suggested to result from the accumulation of *desirable* developmental experiences (Gagné, 2000, 2004). Therefore, comparing the developmental histories and practice biographies of performers with relatively synonymous levels of expertise, who have maximised their potential, could lead to the identification of the determinants necessary for nurturing expertise.

Deliberate Practice: Sufficient or Necessary for Expertise Attainment?

The strong and positive association between volume of domain-specific practice and the attainment of expertise is grounded in research by Ericsson, Krampe and Tesch-Römer (1993). The findings highlighted that expert musicians had accumulated over 10,000 hours of ‘deliberate practice’ by age 20, whilst amateurs had accumulated only 2,000 hours, suggesting that deliberate practice is a precursor of mastery. These findings led to the development of the deliberate practice theory, which advocates a mechanism for developing expertise, contingent on modifying the difficulty of practice commensurate with the skill level of the performer. The theory is centred on the monotonic benefits assumption, whereby the amount of time engaged in deliberate practice is monotonically related to the individual’s acquired performance.

[1] The term “features” is used to describe groups of variables in the thesis.

Deliberate practice must extend a minimum of 10 years, for expertise to be maximised, and should be optimised within three constraints (Ericsson et al., 1993). Firstly, deliberate practice requires sufficient resource, including time, facilities and coaching. Secondly, this practice should not be inherently motivating, nor enjoyable. And finally, deliberate practice should be effortful, and can only be sustained for limited periods as a result, meaning that individuals must avoid exhaustion to maximise gains from this long-term practice.

Despite acknowledgement of deliberate practice benefits for the development of sporting expertise (for a review, *see* Baker & Young, 2014), studies examining the average quantity of total practice undertaken by elite sportsmen during development consistently report significant differences to the suggested 10,000 hours over 10 years, e.g., cricketers: 7273 hrs; wrestlers: 5,865 hrs; footballers: 4,532 hrs; hockey players: 6,403 hrs (Helsen, Starkes, & Hodges, 1998; Hodges & Starkes, 1996; Hornig, Aust, & Güllich, 2014; Weissensteiner, Abernethy, Farrow, & Müller, 2008). The difference between the practice volume of high and low performing cricket batsmen across development stages, casts further doubt over claims that a minimum of 10 years is required for the attainment of expertise (Ericsson et al., 1993). Ford, Low, McRobert, & Williams (2010) found that practice volume only differentiates batsmen between the ages of 13 and 15. This finding suggests that *when*, rather than the *total* practice amount accrued across development, is more important for the development of sporting expertise. Insight from the Australian Olympic pathway shows that the majority (69%) of novice athletes develop into senior elite (national) representatives in less 10 years (Oldenziel, Gagné, & Gulbin, 2004). Furthermore, ‘talent transfer’ initiatives, which involve transferring previous sporting experiences, have led athletes to successfully transition across sports, to represent Australia at the Olympics within short timeframes e.g., 14 months for skeleton (Bullock et al., 2009).

Whilst ‘deliberate’ or ‘domain-specific’ practice is recognised as a precursor of mastery, its application to sport expertise research has led to debate about the necessity for 10,000 hours over 10 years. The theory was developed as an explanatory framework for development of expert performance in finger manipulative and perceptual-cognitive tasks, most relevant for music and chess expertise (Cobley & Baker, 2010; Ericsson et al., 1993; Chase & Simon, 1973). Consequently, the theory fails to discriminate between play, practice, competition, solitary, team based, and coach facilitated activities, and therefore lacks sport specificity, leading to the assumption that these activities are homogenous (Baker, Côté, & Deakin, 2005; Cobley & Baker, 2010; Helsen et al., 1998; Ward, Hodges, Starkes, & Williams, 2007). Furthermore, deliberate practice does not recognise the potential moderating effect of practice microstructure, on the 10,000 hours of practice deemed necessary for developing expertise. This oversight presents a barrier for sport organisers wishing to structure development activities optimally in talent pathways (Holt et al., 2018).

Sport Specialisation and Practice Quantity

Deliberate practice theory drives early specialisation, where sport activity is typically confined to the performance demands of a single sport, with little to no participation activity in other sports (Ericsson et al., 1993). Late specialisation, on the other hand, promotes early diversification and ‘play’ (activities which are fun, free from specific focus and provide immediate gratification), with less emphasis on practice volume pre-specialisation (Cotè, Baker, & Abernethy, 2007). However, emerging research suggests that the relationship between age of specialisation and practice volume is not exclusively linear, since elite athletes have reported undertaking a larger volume of domain-specific practice, compared to sub-elite athletes, despite specialising later in development (Güllich, 2018).

Alternative Talent Development/Performance Models

In addition to deliberate practice theory, there are a number of talent development models originating from the psychology, physiology, education or pedagogy disciplines:

Developmental Model of Sports Participation (Côté et al., 2007); Long-Term Athlete Development (Balyi & Hamilton, 2004); Differentiated Model of Giftedness and Talent (Gagné, 2000, 2004); Athletic Talent Development Environment model (Henriksen, Stambulova, & Roessler, 2010). All of these models have advanced our understanding of expertise development, and filled a gap between application of theory to applied practice. That said, their generic nature presents challenges for identifying 'optimal' practice environments in sport (*see* Phillips, Davids, Renshaw, & Portus, 2010). These challenges can partly be attributed to the additive effects observed within most of the talent development models suggested to develop exceptional performance (*see* Gulbin & Weissensteiner, 2013). However, the influence of the *type*, and *structure* of practice, on *how much* practice is necessary for developing expertise in sport, remains unexplored.

The current literature is limited by a lack of understanding of the interactions taking place between practice activities, and wider developmental histories, to develop expertise. In this regard, Weissensteiner et al. (2008) attempted to identify the developmental history features that contribute to the acquisition of skilled cricket batsmen. Using discriminant function analyses, they aimed to determine features which most accurately discriminated between high or low-performing batsmen (categorised according to anticipation ability). The study highlighted that accrued practice volume was a weak predictor of anticipatory skill. It was concluded that their measures of practice experience could have been insufficiently fine grained, lacking the sensitivity required to capture the critical elements of practice experience that contribute to the acquisition of anticipatory skill. Furthermore, Weissenteiner et al. claimed that skill acquisition could be more closely related to the type of cricket-specific practice undertaken, rather than the quantity, highlighting a need to precisely measure the microstructure of practice (Deakin & Cobley, 2003). Despite all of the above, examinations of the microstructure of sport practice are limited within the expertise development field (e.g., Deakin & Cobley, 2003; Ford, Yates & Williams, 2010; Hüttermann, Memmert & Baker, 2014). Moreover, the influence of the structure of skills-based practice, on the existing relationship between practice quantity and expertise attainment, is less well understood. If future studies are to achieve a better understanding of optimal development environments, and identify durable precursors of expertise, sport-specific examinations of the microstructure of practice activities are warranted (i.e., what was practiced, how this was structured/delivered, and how this practice changed over the course of development).

An Introduction to Contextual Interference

Much of motor learning research pertaining to the microstructure of practice has emanated from controlled laboratory experiments, with unskilled participants, over short learning periods. It is in this setting, that the contextual interference effect on practice has been most widely researched (for a review, *see* Brady, 2008). The contextual interference effect stipulates that multiple skills (or skill variations) are more effectively learned when there is interference present during practice (Battig, 1966). At a practical level, the interference is created by manipulating the structure of practice trials such that skills are learned in either a blocked or random fashion.

Random scheduling involves the learner being required to switch between the skills "randomly" throughout practice, whereas blocked practice requires the learner to practice one skill for a block of repetitions before switching to the other skill (Farrow & Buszard, 2017). The conclusion is that although random practice has detrimental effects on performance during acquisition in the short-term, it facilitates learning in the long-term. This learning is achieved either by encouraging the performer to undertake more elaborate and distinctive processing from one trial to the next (i.e., the elaboration hypothesis, Shea & Morgan, 1979) or through the forgetting and subsequent reconstruction of an action plan each time a skill is performed (i.e., the action plan reconstruction hypothesis, Lee & Magill, 1985). The benefits of random practice appear greatest in the learning of skills that require distinctly different classes of movement actions. However, the benefits of contextual interference also extend to skills which demand the same class of actions (e.g., executing different cricket batting shots), through practicing different parameters (variations) of the skills (e.g., manipulating the area, loft, pace of a batting shot), known as variable practice (Schmidt & Bjork, 1992). This is the opposite to constant practice, where the parameters of a skill are instead fixed. Indeed, the benefits of variable practice are greatest when schedules of practice are somewhat unpredictable (Porter & Magill, 2010). Despite the constraints of this research, random practice, combined with variable practice, may result in superior long-term skill retention, specifically for performance scenarios which are somewhat unpredictable, and demand both the rapid retrieval of movement skills, and extreme accuracy in their execution (i.e., the characteristics of expert performers) (for a review, *see* Monsell, 2003). This type of practice could conceivably aid the development of cricket batsmen with expansive shot repertoires, and an ability to apply effective variation, in rapid response to contextual information presented by a given bowling delivery, and wider situational factors.

Random and Variable Practice: A Mechanism for Optimising Challenge?

Experimental research has demonstrated that high contextual interference can place exceedingly high demands on cognitive processing (Broadbent, Causer, Williams, & Ford, 2017), which could potentially inhibit the benefits typically found to emerge from such practice in laboratory settings. Hence, task difficulty, or skill complexity, relative to the performer, appear central factors in moderating the contextual interference effect (Rendell, Masters, & Farrow, 2009). This position is consistent with the various accounts of learning, whereby learning is more robust when the task difficulty presents an optimal challenge to the performer (e.g., Challenge Point Framework, Guadagnoli & Lee, 2004; Deliberate Practice, Ericsson et al., 1993). Thus, combining the scheduling of random and variable practice, and gradually increasing contextual interference, as a function of task difficulty and skill complexity, could aid the optimisation of challenge for performers (Guadagnoli & Lee, 2004).

The Specificity of Practice Principle

The superior learning associated with random and variable practice conditions likely reflects the benefits of representative learning/practice design (Pinder, Davids, Renshaw, & Araújo, 2011). This extends the specificity of practice principle, which denotes that practice conditions closely matching the movements of the target skill and the conditions of the target context, result in optimal learning (Henry, 1968). In sport, competition constitutes the target context, and competitive performance represents the intended output of learning. Random and variable practice could be particularly beneficial in an open loop sport, such as cricket, where a batsman's output is in direct response to the somewhat unpredictable opposition bowlers' deliveries (Porter & Magill, 2010). More so, when considering that a batsman's ability to adapt, by producing multiple shot types in an unpredictable (random) fashion, and manipulate the direction, loft and pace of shots according to environmental constraints (variability), represents a key performance indicator in international cricket. This benefit is also reflected in recent qualitative research revealing that elite rugby league players were exposed to significantly more match-scenario practice than sub-elite players during development (Rothwell, Stone, Davids, & Wright, 2017). A problem associated with the traditional scheduling of practice, is the development of skills in a non-pressurised environment, as a pre-requisite for subsequent performance of skills in pressurised situations, whereas competition demands the production of skills under pressure (Lawrence et al., 2014). One can reasonably extend specificity of practice principle to consider the multifaceted nature of sport performance, by recognising technical and psychological specificity as separate constructs (Henry, 1968; Lawrence et al., 2014).

The Nature of Practice

There are several features pertaining to the nature of practice activity which are reported to facilitate learning, either before, during or after physical movement. These include the conveyance of instruction and feedback, focus of attention, and the coaching approach adopted. Research has identified that the means of conveying information (via verbal instruction, self-observation, or demonstrations) possess differential effectiveness for skill acquisition, due to individual differences (Hodges & Ste-Marie, 2013; Reid, Crespo, Lay, & Berry, 2007). Consequently, combining observations, demonstrations and verbal cues with physical practice likely reaps learning benefits; providing performers with volition to choose when they receive instruction, offering comparative information, could lead to maximisation of these learning benefits (Hodges & Ste-Marie, 2013).

A prescriptive approach to coaching, consisting of only demonstrations and verbal instructions has been shown to be less beneficial than a constraints-based learning approach. A constraints-based approach challenges performers to learn through exploration and guided discovery, by encouraging them to find solutions to scenarios, and is shown to harness the benefits of implicit learning (Hardy, Mullen, & Jones, 1996; Masters, Poolton, Maxwell, & Raab, 2008; Newell, 1986). Instruction and feedback conveyance is also reported to guide performers' attentional focus. Specifically, focus of attention research has consistently demonstrated that an external focus (i.e., on the movement effect) enhances motor performance and learning more than an internal focus (i.e., on body movements), benefitting both movement effectiveness and efficiency (Wulf, 2013).

Delivery and timing of feedback aims to influence the movement outcome (knowledge of results) and/or the movement pattern (knowledge of performance), and takes the form of augmented (external) or intrinsic (internal) feedback (for a review, *see* Sigrist, Rauter, Riener, & Wolf, 2013). The primary considerations when considering the optimal mode of feedback should include an assessment of both the skill level of the performer, and the amount of available intrinsic feedback associated with the task, as these factors determine the positive role additional (augmented) feedback could play in learning (Anderson, Magill, & Sekiya, 2001; Lawrence, Kingston, & Gottwald, 2013; Sigrist et al., 2013). Current knowledge suggests that augmented feedback should be delivered sufficiently post-knowledge of results for learning processes to occur optimally (Austermann, Robin, Maas, Ballard, & Schmidt, 2008; Anderson, Magill, Sekiya, & Ryan, 2005).

In summary, while there is clearly a place for lab research pertaining to the nature *and* microstructure of practice, the literature has identified a need to validate the findings in the field (Abernethy, 2013; Farrow & Buszard, 2017; Weissensteiner et al., 2008). The technical production of cricket batting skills often needs to be completed under stressful time and psychosocial demands, where the difference between good and poor bat–ball contact can be a matter of a few milliseconds (Abernethy, 1981; McLeod & Jenkins, 1991). Such paradoxical demands highlight challenges, but equally, provide a fertile context for researchers interested in cricket batting skill, and for coaches designing skill development programmes.

Environmental Influences

Whilst there is no question that prolonged practice is necessary for developing expertise, our current (limited) understanding in the field casts doubt on whether it is sufficient, suggesting that wider environmental factors both influence, and contribute to the multifaceted nature of expertise (Güllich et al., 2019).

The relative age effect (RAE) describes an overrepresentation of relatively older (Q1 born) performers within an age-cohort, and is suggested to provide relatively older performers with an early competitive advantage (Helsen, van Winckel & Williams, 2005). This advantage is shown to result from the advanced maturity of chronologically older performers (Barney, 2015; Johnson, Farooq, & Whiteley, 2017). A plethora of research has identified the traditional

RAE within age-groups across a number of sports, e.g., rugby union and cricket (Barney, 2015; Cobley, Baker, Wattie, & McKenna, 2009; Lewis, Morgan, & Cooper, 2015). The Q1 RAE is most likely a consequence of talent pathways' prioritisation of early success in the initial identification and selection of performers (Bailey et al., 2010; Cobley et al., 2009; Lewis et al., 2015).

Barnsley, Thompson and Barnsley (1985) provide the earliest evidence that RAE is associated with career success. They identified that hockey players born earlier in the selection year were more likely to be identified as more 'talented' than their relatively younger counterparts, and were overrepresented in the highest standard of senior competition, i.e., the National Hockey League (NHL). However, recent studies of elite rugby players and cricketers in England have shown that the traditional Q1 RAE typically dissipates by senior-elite level, and even reverses in some cases (Q4 RAE) (Barney, 2015; McCarthy & Collins, 2014; McCarthy, Collins, & Court, 2016). This reversal is attributed to Q4 performers' stronger psychological profile, resulting from their more challenging developmental experiences, compared to their Q1 born counterparts, and could explain the (over)representation of relatively younger players in elite sports programmes (Collins & MacNamara, 2012; McCarthy & Collins, 2014; McCarthy, Collins, & Court, 2016).

Positional demands likely impact on RAE prevalence (Van Rossum, 2006). Despite this, investigations of RAE prevalence at junior and senior-elite levels to date largely neglect potential inter and intra-sport differences, instead assuming homogeneity within sports. Equally, inconsistencies in the criteria developed to benchmark levels of expertise makes it increasingly difficult to draw valid conclusions about the function of RAE in the development of expertise (Coutinho, Fonseca, & Mesquita, 2016; Swann, Moran, & Piggot, 2014).

To the best of our knowledge, the only published research to have examined RAEs in super-elite sportsmen (acclaimed for competing at the highest level of competition consistently) found evidence for differential RAEs across ice hockey positions, with a Q1 RAE identified for male goalies, but not the skater positions (Grondin & Trudeau, 1991). Addona and Yates (2010) later identified a strong RAE for Q1 born Canadian players who had participated in the NHL from 1951 onwards, which remained significant regardless of whether players were treated as homogenous or separated into forwards, defensemen and goalies. However, by increasing the stringency of world's best criteria, to only include players with hall of fame status, the RAE dissipated.

Examination of RAEs at super-elite level appears a fruitful avenue for researchers wishing to better understand the function of RAE in the development of expertise, by firstly identifying whether RAEs highlighted thus far extend beyond youth sport and elite sport into the world's 'super elite' performers. Secondly, to determine whether inter-sport differences emerge from comparisons of RAE prevalence across different sports at the super-elite level. Thirdly, whether assessing RAE prevalence across the different positions presents intra-sport differences. Collectively, these investigations will lead to greater understanding of whether RAE prevalence is dependent on the nature of a sport, and its positional requirements (Coutinho et al., 2016; Van Rossum, 2006). Examinations of the reported underlying processes/mediating factors of RAE, including sport age, maturation, resilience and mental toughness, amongst wider (holistic) approaches, will lead to greatest understanding of the function of the RAE within the overall development of expertise (Bell, Hardy, & Beattie, 2013; McCarthy & Collins, 2014; McCarthy et al., 2016).

Demographics are reported to impact on the development of expertise further. Examination of performers' birthplace revealed that small-to-medium communities provide favourable environments for developing elite athletes, suggesting that 'talent hotspots' may exist (MacDonald, Cheung, Côté, & Abernethy, 2009). However, the majority of birthplace research does not account for regional variations in general population distributions (Wattie, Schorer, & Baker, 2018). Whilst the subtleties of support provisions within a performer's development environment are not well understood, it is clear that prospective super-elite performers benefit from interactions with families, coaches and other support networks during their development (Hopwood, Farrow, MacMahon, & Baker, 2015; Huxley, O'Connor, & Larkin, 2017; Huxley, O'Connor, & Bennie, 2018). For example, having an older sibling is reported to enhance opportunities for play and practice, and exposure to challenges, in developing rivalry and competitiveness (Davis & Meyer, 2008; Taylor, Collins, & Carson, 2017). Despite the overarching importance of early developmental experiences, super-elite athletes are characterised by relatively late entry into organised support programmes; their early absence may partially explain why youth competition is highlighted as a poor predictor of senior success, and an unreliable tool for talent identification (Güllich & Emrich, 2006; Güllich, 2014; Kearney & Hayes, 2018).

A recent study of world's best cricket batsmen demonstrated that age-group performance statistics reflecting learning and adaptability have the greatest relationship with future performance (Barney, 2015). This finding, in conjunction with research demonstrating that higher skilled individuals are better able to 'learn' and modify their technique to improve, presents a compelling argument (Phillips, Portus, Davids, & Renshaw, 2012). Additional retrospective and qualitative research provide further evidence for the importance of ability/capacity to learn (*see* Gould, Dieffenbach, & Moffett, 2002; Hill, 2012). The manner in which learning/adaptability appears most important during the relatively *early* developmental stages is of interest, as this would appear to suggest that this relates to a 'raw' psychological and/or skill acquisition attribute. Thus, cricketers who adapt quickest to the increased skill and psychological demands of transitioning to higher levels of performance, could be earmarked as being high potential by cricket officials, and transition across the pathway sooner as a result. Exactly *how* and *when* superior adaptability manifests in the development of *discipline-specific* cricket expertise is of interest, given their unique physical, technical and cognitive demands.

Summary of Research Limitations

A current divide between research and applied sport practice is highlighted by the dearth of research examining the nature and microstructure of practice in elite performers. This imbalance exists despite being widely believed as important, both from an applied *and* a theoretical point of view (Farrow & Buszard, 2017; Holt et al., 2018). Whilst knowledge pertaining to the nature and microstructure of practice largely stem from lab-based research with novices, it can be reasonably theorised that the precursors identified by the laboratory research facilitate both learning, and the development of expertise in sport (Farrow & Buszard, 2017). However, this hypothesis needs to be tested in the field with a view to finessing the theory and its application to expertise development in the field.

Traditionally, investigations of expertise have focused on isolated domains of expertise, accounting for only part of what is important. This approach lacks an appreciation of the more complex interactions between domains, necessary for a holistic understanding of expertise development (Güllich et al., 2019). Most previous research has restricted investigation to comparing the volume of practice undertaken by groups of performers with distinct levels of expertise (e.g., Ericsson et al., 1993), neglecting the potential moderating effect of the microstructure, and wider developmental features. Limited use of complex statistical analyses within the sport science field, has typically resulted in isolated analysis of independent features, producing one-dimensional findings (Schorer & Elfering-Gemser, 2013). Despite these limitations, independent features have been amalgamated to produce theoretical models of expertise development, e.g., deliberate practice and deliberate play in the Development Model of Sport Participation (DMSP) (Coutinho et al., 2016; Côté et al., 2007).

Previous investigations of isolated neglect the potential interactive effects between developmental features (Güllich et al., 2019). Consequently, there is a need for researchers to identify patterns of features that *make the difference* between relatively synonymous groups of experts, to model the multifaceted and complex nature of expertise, rather than solely *demonstrating differences* between isolated features (Abernethy, 2013). Machine learning methods, such as Artificial neural networks, have been used to examine the extent to which a subset of features predicts the optimisation of talent recruitment and development processes, demonstrating far superior accuracy than offered by linear discriminant analysis (Edelmann-Nusser, Hohmann, & Henneberg, 2002; Pfeiffer & Hohmann, 2012; Pion, Hohmann, Liu, Lenoir, & Segers, 2016). However, as in much of previous research, these studies share the assumption that *all* features initially identified possess importance, due to the absence of ‘feature selection’ procedures, which can mitigate for the fact that feature inclusion could be due to chance, caused by a type 1 error (*see* Güllich et al., 2019).

There is considerable confusion and inconsistency with regard to the criteria used to define the term “elite” or “expert” athlete (Baker, Wattie, & Schorer, 2015; Polman, 2012). This term has been loosely used to describe Olympic gold medallists and world-record holders, and regional and university level athletes, which can make it difficult to draw valid conclusions about expertise, from such studies in which experts are defined using significantly different criteria (Swann et al., 2014). This inconsistency can lead to findings being misinterpreted, and in turn, the misrepresentation of knowledge, thus limiting the identification of important gaps in the field (Coutinho et al., 2016; Swann et al., 2014). Clearly, the lack of robust criteria used to define participants as “expert” athletes threatens the application of research to expertise development in sport, meaning that there is a need to clearly define and operationalise the term “elite” (Baker et al., 2015). In turn, this could help researchers to define their samples along a continuum of ‘eliteness’ or expertise, to improve overall understanding of expertise in sport.

Lack of consideration for inter and intra-sport differences represent a systematic limitation of expertise research (Coutinho et al., 2006; Van Rossum, 2006). This broad-brush approach neglects the unique demands of sports, and their positional/discipline requirements, by treating them as homogenous. It conceals any different development profiles that might be required for the development of expertise across sports, and increases the difficulty of drawing valid conclusions from expertise research further.

Retrospective research designs are limited by the questionable reliability of recall (Côté et al., 2005; Ward, Hodges, Williams, & Starkes, 2004; Helsen et al., 1998). The development and examination of the validity and reliability of The Developmental History of Athletes Questionnaire (DHAQ) identified two key findings relating to the recall accuracy of national athletes, coaches and parents (Hopwood, 2013). Firstly, the relatively low validity and reliability observed from athletes' recall accuracy of participation in organised and informal sports, suggests that the precision with which sporting developmental histories can be recalled is questionable. Secondly, the duplicated information collected from parents and coaches, a method widely used for triangulation of the data (e.g., Côté, 1999; Baker, Côté, & Abernethy, 2003; Hardy et al., 2017), revealed mixed convergent validity of responses. The convergent validity for parent responses was generally poor, whereas the convergent validity for coach responses provided was good to very good. The findings of Hopwood (2013), above all, demonstrate that caution is required in drawing conclusions from the retrospective data of performers and parents in particular, and suggest triangulation may not fully mitigate recall error. That said, investigations of super-elite performers' demographics, practice quantity, and performance-related milestones have been validated within the Great British Medallists study, which triangulated athlete data with parent and coach responses (Güllich et al., 2019; Hardy et al., 2013, 2017). Nevertheless, proactive steps should be taken to improve the trustworthiness of data in future research, particularly in the absence of reliability and validity assessments, and data triangulation. 'Matched pair' designs could prove fruitful in this regard, which have recently been used to explore the practice and psychosocial biographies of British Olympic elite and super-elite athletes (Güllich et al., 2019; Hardy et al., 2013, 2017). Here, the elite and super-elite athletes were paired according to age, competition era and sport type. Whilst the limitations of retrospective research are not eradicated using this design, it can be reasonably inferred that recall inaccuracies owing to age would be approximately equal for both groups, and consequently has potential to improve the relaibility and validity of retrospective expertise development research.

Research Rationale

The present research programme aimed to advance understanding of expertise development, by carrying out the first quantitative analysis of the interaction between the microstructure of practice, and the developmental histories of truly elite sportsmen. A secondary aim was to explore the function of RAE in elite expertise development. This context-specific and holistic research framework was developed in collaboration with ECB pathway officials, and involved a multi-staged piloting process with cricketers and coaches. Non-linear machine learning (pattern recognition) techniques were used to model the multifaceted and complex nature of expertise, with the intention of offering sport scientists a robust way to identify precursors of expertise, and optimal development environments. This approach was chosen to address the limitations of more traditional linear statistical analyses, and to provide a more fine-grained approach, to address the extent to which the relationship between volume of practice and the development of expertise is contingent on organisation of practice. A matched pair design was used to alleviate the limitations of retrospective recall (Güllich et al., 2019; Hardy et al., 2013, 2017). Furthermore, a benchmarking process was developed to accommodate multiple levels of stringency and positions/disciplines, in respect to their physical, technical and cognitive demands, to overcome the inconsistencies in categorising, and differentiating between levels of expertise. All considered, the research aimed to evaluate the contribution of (largely) unexplored domains of expertise (Contextual Interference;

Specificity and Variability of Practice; Constraints-led Learning; and Instruction and Feedback Conveyance; Discipline/Position Specialisation; Adaptability), and their interaction with the domains most widely reported to influence, and contribute to the development of expertise (Demographics; Deliberate Play; Deliberate Practice; RAE; Sport Specialisation; Selection to an Organised Support Programme; Facilities and Coaching Provision; Injury Prevalance) within a truly elite sample. This approach was expected to identify sport and discipline-specific precursors of expertise, predictive of elite performance.

Thesis Structure

The thesis is presented as a series of research papers. This reflects the dual objectives of: (i) generating a thesis; and (ii) writing for publication. For this reason, some information contained in chapter 1 is repeated as introductory information in the empirical chapters (Chapter 2 – 4). A video introducing the PhD programme can be viewed online here (youtube.com/watch?time_continue=1&v=HR9Yd42T2CA). The remainder of the thesis comprises three empirical chapters. Additional information pertaining to the 'Method' sections, and additional empirical evidence is provided in the Supplementary Information section. This information is included for interest, but lies outside of the focal remit of the research aims.

1. Chapter 2 develops and applies a set of stringent criteria to benchmark super-elite expertise, and considers inter and intra-sport differences, by assessing RAE prevalence across the disciplines/positions of cricket and rugby union separately.

2. Chapter 3 applies non-linear machine learning (pattern recognition) analysis to a set of 93 developmental features to holistically examine the predictive power of features, previously suggested to influence the development of expertise, obtained from a sample of sub-elite and elite cricket spin bowlers.

3. Chapter 4 builds on chapter 3, by using a comparison of super-elite and elite cricket batsmen to holistically examine the predictive power of features pertaining to the nature and microstructure of practice, domains of expertise largely unexplored. These features were analysed alongside the developmental features widely suggested to influence expertise development.

4. Chapter 5 includes details evidence of impact and dissemination activities, undertaken during the research programme.
5. Chapter 6 provides a general discussion of the patterns of features that provide greatest discrimination accuracy between relatively synonymous levels of expertise, and an outline of future directions for expertise research.

Chapter 2

New evidence of relative age effects in 'super-elite' sportsmen: a case for the survival <u>and</u> evolution of the fittest[2]

[2] This chapter is published as:

Jones, B.D., Lawrence, G.P., & Hardy. L. (2018). New evidence of relative age effects in 'super-elite' sportsmen: a case for the survival and evolution of the fittest. *Journal of Sports Sciences, 6*, 697-703. doi: 10.1080/02640414.2017.1332420

Abstract

Within sport, the relative age effect (RAE) describes an overrepresentation of players born early (Q1) in a selection year and is highly prevalent within youth sport pathways. This effect is generally shown to dissipate at senior-elite level, however, a dearth of research has investigated the RAE at the 'super-elite' level. The present research assessed the presence of RAE in 'super-elite' sportsmen. Study 1 investigated RAE in the world's best international test cricketers (*N* = 262) over a 20-year period according to robust and stringent 'super-elite' criteria. Results revealed an overall RAE (Q1) when all disciplines were combined. Upon closer examination, this effect was also observed for the batting and spin bowling disciplines, whereas no RAE was found for the pace bowling discipline. Study 2 investigated RAE in super-elite rugby union players (*N* = 691) over a 20-year period. Results revealed the RAE for backs (Q1) and a reversal of the traditional RAE (Q4) for forwards, and when all rugby union positions were combined. These findings provide new evidence of RAEs at the super-elite level and present both inter and intra-sport differences. Potential explanations for these findings are explored, owing to the 'survival and evolution of the fittest' concepts, and the implications for future research and applied practice are presented.

KEYWORDS: physical maturation; cognitive development; skill acquisition; rocky road; resilience

Chronological age grouping in sport competitions may be disadvantageous to children and may hamper their future development (Crawford, Dearden, & Meghir, 2007). That is, adopting chronological age grouping systems results in some children being almost a year younger than some other children in the same group. This process may eventually lead to the relative age effect (RAE), where relatively older children (Q1) are over-represented in comparison to the relatively younger (Q4) in a given age group. In sport, a plethora of research has demonstrated the breadth of the traditional RAE in youth talent pathways across a number of sports, e.g., rugby union and cricket (Barney, 2015; Lewis et al., 2015).

Barnsley, Thompson and Barnsley (1985) provide the earliest evidence that RAE is associated with career success. They identified that players born earlier in the selection year were more likely to be labelled as talented and represent teams in the highest standard of competition, i.e., the National Hockey League (NHL), compared to their relatively younger counterparts. RAE in youth sport teams is often attributed to physical maturation differences (*see* Cobley et al., 2009), where chronologically older athletes are said to be more physically developed than chronologically younger athletes, providing them with a competitive advantage. This competitive advantage is suggested to begin early in development, where players are initially selected (and subsequently remain attached) onto talent pathways based on prioritisation of early success, i.e., physical dominance (Bailey et al., 2010). This is indicative of the *'survival of the fittest'* concept, whereby those who demonstrate early physical maturity best fit the criteria of these selection processes (Christensen, Pedersen, & Mortensen, 2008). Such a bias imposes a significant challenge for Q4 born players wishing to progress along the talent pathway, often resulting in their 'de-selection', where these Q4 born players, who are least physically mature, drop-out of the pathway. Deselected Q4 born players must then remerge as viable acquisitions, by developing resilience from their de-selection experiences, for example, reflective of the '*evolution of the fittest'* concept (Christensen et al., 2008; Hardy et al., 2017).

Recent research has examined RAE across key developmental milestones within professional rugby union and cricket academies (McCarthy, Collins, & Court, 2016). This study revealed a Q1 and Q2 overrepresentation at initial selection into academies. However, a reversal of the RAE (Q3 and Q4) was discovered when assessing the conversation rate of the academy players who ‘graduate’ to represent national level in their respective sports. Similar findings have been reported by Barney (2015), who measured RAE prevalence in cricket across the England and Wales cricket board’s (ECB) entire talent pathway, and highlighted that a Q1 and Q2 RAE existed from U12-U17, but a relatively higher proportion of Q3 and Q4 born players were retained later in the pathway (post U19).

Theoretical rationale for RAE reversals, occurring during the transition from youth to senior level, is observable in previous research. For example, MacNamara, Button, and Collins (2010) identified several psychological characteristics for developing excellence in sport (PCDEs); the extent to which these characteristics are attained may depend on early experiences (Collins & MacNamara, 2012). The Q1 to Q4 RAE reversal has been attributed to the Q4 born players’ stronger psychological profile, developed by challenging developmental experiences, compared to their Q1 born counterparts (McCarthy & Collins, 2014; McCarthy et al., 2016). Furthermore, emerging research has demonstrated that super-elite sportsmen encountered significant traumatic experiences during early development, before achieving international status (Hardy et al., 2017; Rees et al., 2016). Specifically, this revealed that a foundational negative life event, coupled with positive sport-related support were the key differentiators between super-elite athletes (Olympic gold medallists) and elite athletes. Similarly, being a Q4 born player is said to present psychological challenges, as well as physical challenges (Ford & Williams, 2011). Overcoming these challenges may explain why a significant number of Q4 born players are represented in senior-elite sports programmes. This concept is presented in the 'Talent Needs Trauma' framework (Collins & MacNamara, 2012), which argues that the talent pathway should not be a comfortable place to be. Rather, challenges are common in athletes who have developed psychological resilience and toughness, and reached the top. Development trajectories associated with such challenges are referred to as a 'rocky road' (McCarthy & Collins, 2014). For Q4 born players, challenges include training and competing with those of a greater physical stature, or becoming de-selected from a sports programme. Providing these challenges are overcome with sufficient support, they can enhance the development of psychological resilience and toughness, preparing players for further challenges at the highest level (MacNamara, et al., 2010).

To the best of our knowledge, the only research to have examined RAEs in super-elite sportsmen (acclaimed for competing at the highest level of competition consistently) found evidence for differential RAEs across ice hockey positions. A Q1 RAE was identified for male goalies, but no RAE was observed for the skater positions (Grondin & Trudeau, 1991). Addona and Yates (2010) later identified a strong RAE for Q1 born Canadian players who had participated in the NHL from 1951 onwards; this effect remained significant regardless of whether players were treated as homogenous, or separated into forwards, defensemen and goalies. However, by increasing the stringency of world's best criteria, to only include players with hall of fame status, the RAE dissipated.

Examination of RAE prevalence at the super-elite level appears a fruitful avenue for researchers wishing to better understand the function of RAE in the development of expertise, by firstly identifying whether RAEs highlighted thus far extend beyond youth sport and elite sport into the world's 'super elite' performers. Secondly, to determine whether inter-sport differences will emerge from comparing RAE prevalence across different sports at the super-elite level. Thirdly, whether assessing RAE prevalence across the different positions will present intra-sport differences. Collectively, these investigations will lead to greater understanding of whether RAE prevalence is dependent on the nature of a sport, and its positional requirements (Coutinho et al., 2016; Van Rossum, 2006). Furthermore, examination of the reported underlying processes/mediating factors of RAE (including sport age, maturation, resilience and mental toughness), amongst wider (holistic) approaches, will advance understanding of the RAE's function in the overall development of expertise (Bell et al., 2013; McCarthy & Collins, 2014; McCarthy et al., 2016).

The hypotheses of the present research were two-fold: firstly, to test whether RAEs highlighted thus far extend beyond youth sport and elite sport into the world's 'super elite' sportsmen, whilst controlling for a significant limitation of previous research, by considering intra-sport differences through assessing RAE prevalence across the different positions. Secondly, to determine whether comparing RAE across different sports at the super-elite level will present of inter-sport differences. That is, consideration of the unique physical, technical and cognitive demands attached to different sports may assist in identifying *'why'* possible RAEs exist in super-elite performers. Furthermore, we can begin to make inroads in testing the hypotheses that Q1 born players' early domination, continues to the super-elite level, indicative of the 'survival of the fittest' concept (Christensen et al., 2008). Or, conversely, whether there are mechanisms present in-between these expertise levels that may explain a Q4 overrepresentation, indicative of the 'evolution of the fittest' concept (Christensen et al., 2008; Hardy et al., 2017). This approach could collectively highlight how RAE prevalence is dependent on the nature of a sport, and positional requirements.

Study 1

Method

Participants. The initial sample (*n* = 262) consisted of male (past and present) cricketers, sampled from 9 different International Test teams between 1994 and 2014 (*see* Supplementary Information for list of teams sampled). International Cricket Council (2014) online player ranking data was adopted as the initial criteria for super-elite status across the different disciplines, on the basis that the players had been recorded in the top 30 in the World in Test format within the 20-year period specified. Cricket disciplines were categorised as batsmen, spin bowlers, pace bowlers, bowlers combined and all disciplines[3] combined. Subsets of these participants were then identified using 11 criteria of increasing stringency developed from an analysis of the datasets. These criteria were developed with support from ECB national coaches, in recognition of the inconsistent criteria previously used to define level of expertise (Baker et al., 2015; Coutinho et al., 2016; Swann et al., 2014) and resulted in *n* decreasing from 262 (least stringent) to 110 (most stringent) (*see* Table 1). The present criteria served as a means of creating distinctions between levels of super-elite performance, in order to demonstrate the robustness of any potential effects found.

Procedure. The study received institutional ethics approval. The first task was to establish suitable DOB cut-off criteria for each country. This was determined by the competitive calendar for each country, which was obtained directly from the international cricket boards. Participant details were cross tabulated according to player's DOB quarters (where Q1= the oldest players and Q4 = youngest players) (*see* Supplementary Information). Distribution frequencies were categorised according to the cricket disciplines: batsmen, spin bowlers, pace bowlers, bowlers combined, and all disciplines combined, aligned to the 11 variations of super-elite status criteria of increasing stringency (Table 1).

[3] NB. The wicket-keeping discipline was excluded from the present study due to there being an insufficient sample size represented at the super-elite level.

Table 1. Degrees of criteria for cricket's super-elite criteria and the resultant sample sizes

Stringency	Criteria of Super-elite	n
1 (least)	Ranked top 30 in world; Last 20 years	262
2	Ranked top 30 in world; Last 20 years; Held highest ranking achieved for greater than 1 month	98
3	Ranked top 30 in world; Last 20 years; Played a minimum of 50 international test matches	125
4	Ranked top 30 in world; Last 20 years; Spent minimum of 5 years in the top 30 rankings	92
5	Ranked top 30 in world; Last 10 years; Spent minimum of 1 month in the top 30 rankings	193
6	Ranked top 30 in world; Last 10 years; Spent minimum of 3 years in the top 30 rankings	103
7	Ranked top 20 in world; Last 20 years	204
8	Ranked top 20 in world; Last 10 years; Spent minimum of 1 month in the top 20 rankings	157
9	Ranked top 20 in world; Last 10 years; Spent minimum of 3 years in the top 20 rankings	121
10	Ranked top 10 in world; Last 20 years	147
11 (most)	Ranked top 10 in world; Last 10 years; Spent minimum of 1 month in the top 10 rankings	110

Results

Omnibus Chi-Square Analyses

Given that existing definitions and measurement of super-elite status are somewhat arbitrary, we identified a range of criteria to define super-elite status, and conducted omnibus Chi-square analyses. The analyses involved initial examination of the quarter distributions data (*see* Supplementary Information). Specifically, the frequency of Q1 and Q4 overrepresentations were analysed for each discipline across the 11 different criteria. The magnitude of RAEs was also established by computing the effect size (Cohen's *d*). Cohen's *d* represents the ratio between the Chi-square value (χ^2) and the sample size (*n*) (Cohen, 1988).

Batsmen. Examination of the distribution frequencies for batsmen revealed that Q1 was significantly overrepresented in 9 out of the 11 criteria (χ^2 (1, n = 11) = 4.45, p = .03, d = 0.41). Q4 was *not* overrepresented in any of the 11 criteria, and was in fact significantly underrepresented **(**χ^2 (1, n = 11) = 11.00, p < .01, d = 1.00). The number of batsmen in each criterion ranged from 133 (least stringent) to 38 (most stringent).

Spin Bowlers. Examination of the distribution frequencies for spin bowlers revealed that Q1 was significantly overrepresented in 10 out of the 11 criteria (χ^2 (1, n = 11) = 7.36, p < .01, d = 0.67), whereas Q4 was significantly underrepresented in all 11 criteria **(**χ^2 (1, n = 11) = 11.00, p < .01, d = 1.00). The number of spin bowlers in each criterion ranged from 40 (least stringent) to 13 (most stringent).

Pace Bowlers. Examination of the distribution frequencies for pace bowlers revealed that Q1 was overrepresented in 7 out of the 11 of the criteria; however, this was *not* significant (χ^2 (1, n = 11) = 0.82, p = .37, d = 0.07). Q4 was *not* significantly overrepresented *nor* underrepresented across the criteria (χ^2 (1, n = 11) = 0.82, p = .37, d = 0.07).

Bowlers combined. Examination of the distribution frequencies for bowlers combined revealed that Q1 was significantly overrepresented in all 11 criteria *(*χ^2 (1, n = 11) = 11.00, p <

.01, d = 1.00), whereas Q4 was significantly underrepresented in all 11 criteria (χ^2 (1, n = 11) = 11.00, p < .01, d = 1.00). The number of bowlers in each criterion ranged from 129 (least stringent) to 41 (most stringent).

All disciplines combined. Examination of the distribution frequencies for all disciplines combined revealed that Q1 was significantly overrepresented in all 11 criteria (χ^2 (1, n = 11) = 11.00, p < .01, d = 1.00), whereas Q4 was significantly underrepresented in all 11 criteria (χ^2 (1, n = 11) = 11.00, p < .01, d = 1.00). The number of cricketers in each criterion ranged from 262 (least stringent) to 92 (most stringent).

Discussion

Results revealed a Q1 RAE for all disciplines combined in super-elite cricketers, spanning 9 International Test teams over a 20-year period. These findings present differential effects, when analysing the individual disciplines in isolation. A Q1 RAE was evident for batsmen, spin bowlers and bowlers combined, but no RAE was found for pace bowlers. These differential effects further emphasise the importance of considering the positional requirements of a sport when measuring RAE, given that the requirements can be fundamentally different in nature, and impact RAE prevalence accordingly. Our data add new evidence to scant research reporting the traditional RAE at the super-elite level (e.g., Grondin & Trudeau, 1991).

A direct comparison between the RAE prevalence observed in cricket's super-elite, and the RAE prevalence of a different sport, where physicality is fundamental throughout the talent pathway, will add greater certainty to explanations provided for these findings, by considering inter and intra-sport differences. Study 2 will draw comparisons to study 1, by assessing RAE prevalence in super-elite rugby union players, where exceptional physical maturation during early development are likely particular beneficial, and remains desirable throughout the talent pathway. This will assist in (indirectly) identifying *'why'* differential RAEs exist in super-elite performers, and begin to highlight how RAE prevalence may be dependent on the nature and positional requirements of a sport.

Study 2

Method

Participants. The competitive calendar DOB cut-off dates for each country were obtained following correspondence with World Rugby officials. The initial sample of players (*n* = 690) consisted of male (past and present) international Rugby Union players. Players were selected from the top 10 internationally ranked teams, using the World Rugby official team rankings as of December 31st, 2014 (World Rugby, 2014) (*see* Supplementary Information for list of countries sampled). Players from these teams were then selected on the basis that they had accumulated a minimum of a single cap between 1994 and 2014. A screening process then took place to determine criteria of incremental stringency for super-elite using player frequency statistics. Subsets of participants were identified for each position using criteria of increasing stringency, developed from an analysis of the datasets, and resulted in *n* decreasing from 690 (least stringent) to 87 (most stringent) (*see* Table 2). Rugby Union positions were categorised as backs, forwards, and all positions combined.

Table 2. Degrees of criteria for rugby union' super-elite and the resultant sample sizes

Stringency	Criteria of Super-elite	n
1 (least)	Minimum of 20 caps; Last 20 years	691
2	Minimum of 20 caps; Last 20 years; Minimum of 50% team victory rate	495
3	Minimum of 20 caps; Last 10 years	300
4	Minimum of 20 caps; Last 10 years; Minimum of 50% team victory rate	198
5	Minimum of 30 caps; Last 20 years	489
6	Minimum of 30 caps; Last 20 years; Minimum of 50% team victory rate	354
7	Minimum of 30 caps; Last 10 years	207
8	Minimum of 30 caps; Last 10 years; Minimum of 50% team victory rate	131
9	Minimum of 40 caps; Last 20 years	352
10	Minimum of 40 caps; Last 20 years; Minimum of 50% team victory rate	255
11	Minimum of 40 caps; Last 10 years	135
12	Minimum of 40 caps; Last 10 years; Minimum of 50% team victory rate	87
13	Minimum of 50 caps; Last 20 years	248
14 (most)	Minimum of 60 caps; Last 20 years	172

Procedure. Given that there are no official rugby union player rankings, the first stage of the study involved developing criteria for super-elite using the player statistics, and specifically the number of international caps. It was then recognised that number of caps alone may not be fully representative of super-elite players, and may instead have included a vast proportion of players with a proven longevity in the 'less successful' international teams within the top 10. As such, an additional criterion was implemented which excluded players whose victory rate fell below the combined average of the top 10 teams (50%) alongside the number of caps they held (where sufficient sample sizes allowed this)[4] . The additional stringency meant that the criteria now allowed for players who had played an integral part in the success of teams, over and above that of the average success of the top 10. This resulted in the formulation of criteria consisting of 14 degrees of super-elite (1 = least stringent, 14 = most stringent) (Table 2), which was then applied to the birth quarters of the competitive calendar for the 10 countries identified, to subsequently assess the prevalence of RAE in the sample.

Results

Omnibus Chi-Square Analyses

We defined super-elite status using a range of criteria, and conducted omnibus Chi-square analyses. The analyses initially involved examination of the quarter distributions raw data (*see* Supplementary Information). Specifically, the frequency of Q1 and Q4 overrepresentations were analysed for each position across the 14 different criteria.

Backs. Examination of the distribution frequencies for backs revealed that Q1 was significantly overrepresented in 11 out of the 14 of the criteria (χ^2 (1, n = 14) = 4.57, p = .03, d

[4] Success rate was calculated using the combined average victory rate of each team within the top 10 rankings based on a 20 game period (2012 – 2014). This criterion was not possible for stringency levels 13 and 14 due to an insufficient sample size for further chi-square analysis. This may reflect the super-elite's longevity at international level. That is, number of caps alone may serve as a sufficient metric of super-elite status once players have attained a significant number of caps (i.e., 50+), establishing themselves as international players.

= 0.33), whereas Q4 was significantly underrepresented in all 14 criteria (χ^2 (1, *n* = 14) = 14.00, *p* < .01, *d* = 1.00). The number of backs in each criterion ranged from 304 (least stringent) to 35 (most stringent).

Forwards. Examination of the distribution frequencies for forwards revealed that Q1 was significantly underrepresented in all 14 criteria (χ^2 (1, *n* = 14) = 14.00, *p* <.01, *d* = 1.00), whereas Q4 was significantly overrepresented in 11 out of the 14 of the criteria (χ^2 (1, *n* = 14) = 4.57, *p* = .03, *d* = 0.33). The number of forwards in each criterion ranged from 389 (least stringent) to 52 (most stringent).

All positions combined. Examination of the distribution frequencies for all positions combined revealed that Q1 was significantly underrepresented in 12 out of the 14 criteria (χ^2 (1, *n* = 14) = 7.14, *p* <.01, *d* = 0.51). Q4 was overrepresented in 8 out of the 14 criteria, however, this was *not* significant (χ^2 (1, *n* = 14) = 0.29, *p* = .59, *d* = 1.00). Follow-up Chi-square analysis was required to compare the prevalence of the distribution frequencies of Q1 and Q4, and this analysis revealed that the number of Q4 overrepresentations observed was significantly greater than the number of Q1 overrepresentations observed (χ^2 (1, *n* = 14) = 7.14, *p* = < .05, *d* = 0.51). The number of players in each criterion ranged from 691 (least stringent) to 172 (most stringent).

Discussion

Study 2 revealed that backs were subject to the traditional RAE (Q1). For forwards, a reversal of the traditional RAE was identified; players born later in the year (Q4) were significantly over-represented. Additionally, in the case of all positions combined, Q4 born players were also overrepresented. These findings extend the findings of study 1, revealing intra-sport differences in RAEs. Specifically, the Q1 RAE observed for rugby union super-elite backs provides partial support to the Q1 RAE shown across the batting and spin bowling individual cricket disciplines.

The investigation of individual positions/disciplines in the present studies has enabled the measurement of RAE prevalence, whilst also considering inter-sport differences within cricket and rugby in isolation. The general discussion will explore how the inter-sport differences (and overlap) initially highlighted may be explained by the intra-sport differences evident across cricket and rugby union pathways. This will edge researchers and practitioners alike ever closer to knowing *why* RAEs exist at the super-elite level in sport, and identify the implications of this top-down approach for talent identification and development processes.

General Discussion

The present studies examined the presence and prevalence of RAEs in world's best cricketers and rugby union players over a 20-year period. A set of stringent criteria for defining super-elite was adopted, together with categorisation of key positions, to explore the (previously neglected) potential for intra-sport RAE differences. Findings revealed a Q1 RAE for batsmen, spin bowlers, bowlers combined, and when all disciplines were combined, but no RAE was found for pace bowlers. Whilst a Q4 RAE was observed for all the rugby union positions combined, differential RAEs were observed in the case of the individual positions; a Q1 RAE was observed for backs and a Q4 RAE was observed for forwards. These findings provide new evidence of RAEs in super-elite sportsmen.

Previous research has demonstrated that a widespread Q1 RAE exists across junior sports (for a review *see* Baker, Schorer & Cobley, 2010*;* Cobley et al., 2009), however this effect has been reported to dissipate at the senior-elite level (Barney, 2015; McCarthy et al., 2016). However, in addressing the methodological constraints of treating disciplines and positions as homogenous (Van Rossum, 2006), our study offers evidence that sport and positional-specific RAEs occur at the super-elite level. We offer two potential explanations for this recurrence of RAEs at the super-elite level, by considering how the positional requirements of cricket and rugby union may precipitate the developmental trajectories of super-elite sportsmen.

The back position, where a Q1 RAE is present at the super-elite level, is contingent on a range of tactical elements. And, given that the benefits of physical maturation have dissipated by this point, backs need to make use of tactical awareness, to problem solve, by formulating strategies to overcome the sheer physicality of the likely fully developed opposition forwards; the weighting of cognitive development develops over several years (Myer et al., 2013). Consequently, it may not be possible to develop the necessary attributes to overcome this mismatch post-childhood. Sound technique is of critical importance for spin bowlers and batsmen, and the proprioceptive benefits associated with early practice is deemed vital in the skill acquisition process (Such, Felton & King, 2012). Competition experience aids cognitive development further, resulting in the reliable production of the necessary skills on demand (Masters, 2013). Ultimately, this could mean that the best performing Q1 born players (who have been ever-present in the pathway), progress to become super-elite players, reflective of the ‘survival of the fittest’ concept.

It appears that the bigger disadvantage for forwards is being advantaged too early. That is, early selection bias, focusing on physicality alone, may disadvantage forwards, as it is based on physical factors that are not sustainable for the future. Specifically, if the bias towards Q1 born players is reflected in junior team selections, these existing Q1 born forwards may no longer be in the strongest position by the time physical maturation differences become less marked. By this point, the Q4 born players who have ‘survived’ within the pathway, or entered later, may possess both the physicality and the mindset to succeed (Coutts, Kempton, & Vaeyens, 2014; McCarthy & Collins, 2014; McCarthy et al., 2016). The success of these Q4 born players is attributed to the ‘rocky road’ development trajectory, where maintaining a desire to train and compete with those of a greater physical stature is likely to develop a degree of psychological resilience and toughness that will prepare players for the challenges faced at the pinnacle of the sport (Collins & McNamara, 2012; Ford & Williams, 2011; MacNamara et al., 2010). These combative attributes take precedent in the forward position, and the development of these attributes could explain why we see an overrepresentation of Q4 born forwards at the super-elite level, indicative of the ‘evolution of the fittest’ concept.

The lack of RAE observed for super-elite pace bowlers suggests alternative explanations. Pace bowling is contingent on both physicality and technique, and given how pace bowlers are required to deliver high speed deliveries which generate bounce, possessing greater height, arm span and strength during early development are likely to provide a strong foundation for developing technique. However, poor technique can lead to inconsistency and injuries, and thus, the conversion rate of Q1 born pace bowlers from junior to senior level may not be linear. It is likely that a proportion of Q4 born pace bowlers will have benefited from a non-linear development, owing to the early bias towards more physically mature Q1 born players (Coutts et al., 2014; McCarthy & Collins, 2014; McCarthy et al., 2016). The need to possess physicality, coupled with robust technique, suggests that a proportion of Q4 born pace bowlers may remain ever-present along the pathway, or indeed re-enter the pathway. As a result, the relatively younger Q4 born pace bowlers who demonstrate robust technique early, with added potential for further growth, are likely viewed as players with high potential, subsequently reducing the disparity in birth quarter conversions from junior to elite level.

The present study offers explanations for the differential RAEs observed in super-elite sportsmen, based on extant literature, and offers further insight, through exploring the fundamental differences that exist across sports, and their positions/disciplines. Future research would benefit from a sport-specific, systematic longitudinal study which measures the reported main causes of RAEs (e.g., resilience, maturation) in youth players upon entry into sports programmes (baseline measure). The conversion rates of player progression along the pathway should also be tracked and recorded simultaneously, across a number of significant pathway milestones, relative to their birth quarters. Sport administrators may then wish to repeat the baseline measures to ascertain whether any changes have occurred in players' measures, based on developmental experiences. This would enable researchers to attach greater certainty to explanations of *why* disparity in RAE prevalence exists across the expertise continuum. The current message to sport practitioners is that changing early selection criteria, to reduce the emphasis placed on physical maturation, will reduce RAE bias, and will provide most players with the best opportunities to excel, in effect widening the selection pool. In this regard, the recent application of bio-banding, a method of grouping junior players according to maturational status, as opposed to chronological age (Cumming, Lloyd, Oliver, Eisenmann, & Molina, 2017), could well assist with promoting the development and well-being of young athletes, exposing athletes to a broader range of challenges and learning contexts. However, RAE is a contributing factor in the efficient turnover of players who do excel, whereby those who do succeed have benefited from the disparity in physical and cognitive maturity within their age cohort. In the case of the Q4 born super-elite forwards, they are exceptional, and in the absence of initial RAE bias, they may not have been exceptional. Consequently, we suggest that application of bio-banding should be limited to a confirmatory process, and applied concurrently alongside existing talent development processes, but should not substitute chronological age grouping at present.

Conclusion

In summary, it appears that the greater the emphasis placed on physical capability in a given sport, the less likely the Q1 RAE will extend from junior to senior level, due to the ongoing potential of Q4's. This is demonstrated by the Q4 RAE observed for super-elite rugby union forwards, indicative of the 'evolution of the fittest' concept; the overcoming of significant challenges (associated with the disparity in physical size during development) likely fosters resilience, and a mindset for achievement at the highest level**.** Furthermore, we conclude that the less weighting placed on physical characteristics, the more likely the Q1 RAE is to persist. This is supported by the widespread Q1 RAE observed for cricket batsmen, spin bowlers and rugby union backs. These findings support the 'survival of the fittest' concept, where prolonged presence throughout the pathway (due to initial Q1 maturity bias) facilitates the development of the cognitive component required for backs. This longevity likely provides cricketers with a platform to develop the technique required to cope with technical demands at the highest level.

Chapter 3

The identification of ‘game changers’ in England Cricket’s developmental pathway for elite spin bowling: A machine learning approach[5]

[5] This chapter is submitted for publication as:
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Abstract

Research exploring the development of expertise has mostly adopted linear methods to identify precursors of expertise, assessing statistical differences between groups of isolated variables by way of attaching importance to variables, e.g., deliberate practice hours (Ericsson et al., 1993). However, confining the complex nature of expertise development to linear investigations alone may be overly simplistic. Consequently, to better understand the multidimensional and complex nature of expertise development, we applied (non-linear) pattern recognition analyses to a set of 93 features obtained from a sample of 15 elite (International) and 13 sub-elite (First-class county) cricket spin bowlers. Our study revealed that a subset of 12 developmental features, from a possible 93, discriminated between the elite and sub-elite groups, with very good accuracy. The 12-feature subset forms a holistic development profile, reflecting the elite's earlier engagement in cricket, greater quantity of domain-specific practice and competition, and superior adaptability to new levels of senior competition. Evidence for the external validity of this new model was offered by its ability to correctly classify data obtained from five unseen spin bowlers with 100% accuracy. In light of these quantitative findings, the content of qualitative data provided by the cricketers was subsequently analysed to obtain a deeper understanding of the features that discriminate between the elite and sub-elite groups.

KEYWORDS: talent identification; talent development; pattern recognition; feature selection; deliberate practice; resilience

The development of expertise is complex, and therefore requires a holistic approach to fully explore its multifaceted nature (Pearson, Naughton, & Torode, 2006; Abernethy, 2013). Despite this, investigations of expertise have focused on isolated domains of expertise, accounting for only part of what is likely important. This approach lacks an appreciation of the more complex interactions between the domains, necessary for a holistic understanding of expertise development (Güllich et al., 2019). Most previous research has restricted investigation to comparing the volume of practice undertaken by performers with distinct levels of expertise (e.g., Ericsson et al., 1993), neglecting the potential moderating effect of wider developmental features. This, combined with limited use of complex statistical analyses within the sport science field, has typically resulted in isolated analysis of independent features, producing one-dimensional findings (Schorer & Elfering-Gemser, 2013). Despite these limitations, independent factors have been amalgamated to produce theoretical models of expertise development, e.g., deliberate practice and deliberate play in the DMSP (Coutinho et al., 2016; Côté et al., 2007). In light of these limitations, the primary aim of the present study was to apply machine learning techniques, to identify the multifaceted pattern of developmental features (variables) that discriminate between elite and sub-elite cricket spin bowlers most accurately.

Historically, elite sport organisations have also experienced difficulties, namely in implementing research findings, possibly because some studies have not provided applied recommendations, or lack context specificity in their approach. Generic recommendations often prevent research from positively impacting on sporting talent pathways (Holt et al., 2018), due to the mismatch between these generic recommendations, and the unique and highly complex demands of each sport, and their positions/disciplines (Jones et al., 2018). This historic imbalance is likely due to the production and advocation of blanket ‘optimal’ sport performance models within the expertise development literature (Phillips et al., 2010).

Existing sport performance models, such as the Differentiated Model of Giftedness and Talent (DMGT) (Gagné, 2004), do advocate a multi-disciplinary approach to developing expertise, but nevertheless, promote a standardised approach. The DMGT lacks an explanatory rationale to underpin a dynamic and multi-dimensional basis for expertise, or the process of identifying and developing talent (Phillips et al., 2010). The DMGT's conditional innate (genetic) basis for developing expertise is different to the DMSP (Cotè et al., 2007), where possessing 'superior' innate factors are not necessarily conditional for the development of expertise. Instead, this model stipulates that the 'sampling stage' (stage 1 of 3), between the ages of 6 and 12, should promote deliberate play; activities which are fun, free from specific focus and provide immediate gratification (Cotè et al., 2007). The final stage, known as the 'investment stage' (age 16+), focuses on undertaking specialised practice in the primary sport. This stage is consistent with research denoting that 10,000 hours of deliberate practice (activities which are effortful, focused, goal directed, and not inheritably enjoyable) leads to the development of expertise (Ericsson et al., 1993). The 'investment stage' is contingent on the preceding inter-sport 'specialisation stage' (ages 13-15).

Specialisation describes the prioritisation of personal resources towards a sport (Cotè et al., 2007), and is suggested to accelerate the development of expertise (Ericsson et al., 1993; Ford, Ward, Hodges, & Williams, 2009; Ward et al., 2004). By definition, existing development models encompassing specialisation, such as the DMSP, do not consider intra-sport differences, i.e., differences between positions/disciplines, meaning that intra-sport specialisation is not currently recognised as a valid construct of specialisation. Intra-sport differences may have been overlooked historically given how the impact of diversification *within* sports (i.e., intra-sport diversification) is largely unexplored, and likely less well understood among researchers and coaches as a result (e.g., Voigt & Hohmann, 2016). Current standardised sport specialisation guidelines, coupled with the lack of consideration for intra-sport specialisation, has contributed to our limited understanding of 'desirable' sport and discipline-specific development environments (Güllich et al., 2019; Rees et al., 2016).

Emerging research comparing the multi-disciplinary biographies of serial medalling (super-elite) athletes against those of elite athletes has made significant advancements in the area of expertise development (The Great British Medallists Study; Güllich et al., 2019, Hardy et al., 2013). This study analysed the predictive power of a large pool of features, relative to each other, producing a smaller subset of features containing the highest predictive power. However, the coarse-grained approach employed in The Great British Medallists Study sacrificed detail in favour of breadth of exploration. Merging multiple sports within the analysis meant that the discriminating power of features relating to practice was diminished due to differences between sports. In the sport of cricket, the physical, technical, tactical and psychological requirements of the disciplines are so fundamentally different, they are considered as different sports in their own right (Jones et al., 2018). Consequently, there exists a need for pathway-specific research in cricket that considers disciplines/positions as separate entities, to better understand precursors of expertise in cricket, and provide context-specific recommendations for the ECB pathway.

The difficulties of developing elite cricketers in England, within the spin bowling discipline in particular, are well documented, not least due to the historical scarcity of spin bowlers competing at international level (Richardson, 1934; Coyne, 2016). The severity of the issue is compounded by comparison to other nations' surplus of spin bowlers, reflected in their overrepresentation in the bowling world player rankings (International Cricket Council World Rankings, 2017). The dominance of these spin bowlers is often attributed to the warmer climates of their development origins; warmer climates are shown to aid the mechanics of applying revolutions on the ball using the fingers or wrist, and lead to drier wickets that are receptive to lift and turn, cumulatively fostering the development of spin bowlers (Nodehi-

Moghadam, Rahnama, Habibi, & Dehghani, 2015). This point is particularly pertinent in the Indian sub-continent, where spin bowling is considered the first line of attack (Silva, Perera, Davis, & Swartz, 2016). The colder climates of England and Wales are very different, where the wickets are flat, offering little lift and turn, meaning that pace is inherently considered the first line of bowling attack, rather than spin. This disparity in climates poses environmental challenges for the subsequent progression of spin bowlers. That is, whilst the development structures within warmer climates appear to facilitate, and encourage the development of pure spin bowlers, multidiscipline spin bowlers who possess batting (all-round) potential may be favoured over pure spin bowlers within the talent pathway in England and Wales. Spin bowling is an art; producing spin, rhythm, control and flight on the ball are all fundamental aspects, taking years of craft to develop a repeatable action and consistent bowling outcomes (Such et al., 2012). Unlike pace bowling, where generating pace and bounce are key, spin bowling demands sound technique to deceive batsmen, requiring patience and a degree of resilience.

The documented talent pathway in England and Wales begins with county cricket academies. Players progress through the age groups, before graduating to become Second XI, and eventually, First XI County senior professionals. Players demonstrating high potential the earliest will likely be selected for prestigious regional tournaments along this course, before entering the Young Lions (international U19s team). The Lions senior team represents the last step on the pathway to becoming an international player. The structured nature of talent pathways makes it increasingly important for talent identification processes to function optimally, especially in the early identification of spin bowling potential. Given the differential rates of development evident in prospective international cricketers, it is important that players who are deselected from talent development programmes along the pathway are continually considered for reselection (Barney, 2015). At present, the developmental trajectories of English spin bowlers are not empirically known, owing to the scarcity of expertise development research in cricket. Furthermore, it could be hypothesized that the development of spin bowlers differs from that of neighbouring cricket disciplines (i.e., batting, pace bowling and wicket-keeping), given the discipline's emphasis on technique, for example. In this regard, a study exploring the development of spin bowlers will likely have implications for the development structures of existing cricket academies, leading to the identification of desirable practice environments, and subsequently informing the production of elite spin bowlers from academies.

A study of Cricket Australia's spin bowling development structure, at junior, state and international levels found that the development of spin bowlers is delayed, relative to other cricket disciplines (Mann, 2014). This was demonstrated by a later peak in spin bowlers' performance, and was attributed to flaws within talent development environments, perhaps best illustrated highlighted by the low volumes of spin specific-practice and competition overs bowled. For this reason, it is deemed particularly difficult for 'genuine' spin bowlers to break into Cricket Australia's talent pathway. A commonality shown across the development of these spin bowlers, were the number of setbacks experienced. Setbacks were most prevalent transitioning from junior to senior cricket, demonstrating that there may be both an imbalance in the technical development of Australian spin bowlers, and an increasing need for resilience.

Research comparing conversion rates of county academy cricketers who graduate to the senior international team in England and Wales, measuring the prevalence of the relative age effect (RAE), concluded that the development of cricketers reflects a complex and non-linear journey (McCarthy et al., 2016). RAE refers to an overrepresentation of relatively older players within age-group teams and academies, and is attributed to accelerated physical maturation (Barney, 2015; McCarthy et al., 2016). However, a reversal, favouring relatively younger players was observed for those selected for the senior international teams, suggesting these (prospective) senior international players have benefitted from overcoming the challenge of training and competing with peers of a greater physical size throughout development. Relatively younger spin bowlers who overcome the RAE likely demonstrated resilience, among other psychological characteristics required to become an elite spin bowler (Jones et al., 2018). Moreover, adaptability to new levels of performance has been identified as a key predictive factor of progression along various stages of the cricket talent pathway (Barney, 2015), supporting the notion that the journey to expertise attainment is non-linear.

Previous investigations of isolated features have disregarded the potential interactive effects of individual features of development (Güllich et al., 2019). Consequently, there is a need for researchers to identify features that *make the difference* between relatively synonymous groups of experts, reflecting the multifaceted and complex nature of expertise, rather than solely *demonstrating differences* between isolated features (Abernethy, 2013). Machine learning methods, such as Artificial neural networks, have been used to examine the extent to which a subset of features predicts the optimisation of talent recruitment and development processes, demonstrating far superior accuracy than offered by linear discriminant analysis (Edelmann-Nusser et al., 2002; Pfeiffer & Hohmann, 2012; Pion et al., 2016). However, as in much of previous research, these studies share the assumption that *all* features initially identified possess importance, due to the absence of 'feature selection' procedures, which can mitigate for the fact that feature inclusion could be due to chance, caused by a type 1 error (*see* Güllich et al., 2019).

The present study addresses existing limitations, by employing state of the art non-linear pattern recognition techniques, to explore the complexities behind *'what makes the difference?'* in the developmental trajectories of elite cricket spin bowlers, setting them apart from the sub-elite. Furthermore, a qualitative component was employed to enable deeper understanding of any features that may discriminate between the elite and sub-elite groups, identified in the quantitative analyses. This constituted a relatively unstructured qualitative interview schedule, designed to explore the development of spin bowlers, alongside the existing quantitative component of the study. It was anticipated that the mixed method approach would produce a holistic and fine-grained profile, containing the strongest precursors of elite spin bowling expertise, by discriminating between elite and sub-elite spin bowlers, and thereby informing the ECB's talent identification and development framework.

Method

Participants

The sample comprised 15 elite and 13 sub-elite past and present spin bowlers, with an age range of 24 to 75 years. Elite spin bowlers (M_{age} = 43; *SD* = 14.32) had represented the England international team in test and/or limited over formats (M_{caps} = 37; *SD* = 43). The sub-elite spin bowlers (M_{age} = 40.62; *SD* = 7.30) had endured a prolonged career in professional county cricket (M_{caps} = 261; *SD* = 47), but had not represented England at senior international level, and were deemed unlikely to beyond reasonable doubt, owing to their age, coupled with the professional opinion of the ECB's National Lead Spin Bowling Coach. The clear distinction in spin bowlers' level of expertise allowed for an accurate examination of developmental features that may be of importance in becoming an elite (international) player, and addressed inconsistencies shown across existing criteria defining levels of expertise in previous research (Baker et al., 2015; Coutinho et al., 2016; Swann et al., 2014).

Measures

Spin Bowlers Development Interview Schedule. An interview schedule was specially developed by the researchers for this study based on methodologies that had been successfully used in previous research (e.g., Hardy et al., 2017) (*see* Supplementary Information). Prior to this, a consultation process between the researchers and the National Lead Spin Bowling Coach took place. Specifically, the authors outlined the aspects of development that were of theoretical interest to the study, and the National Lead suggested aspects of development that were of interest to the ECB for the practical development of spin bowlers. The resulting interview was sub-divided and ordered into quantitative and qualitative questions.

Quantitative Measures. The data obtained from the quantitative section of the interview were directly inputted into Microsoft Excel during the interview, across each of the four sections outlined below (*see* Supplementary Information for all features):

1. Demographics: Birth quarter; birthplace; sibling order effect; type of schooling; educational milestones.
2. Structured sporting history: Quantity of organised coach-led cricket practice/training; quantity of unsupervised cricket practice; 'spin bowling-specific' organised practice; competition experience; competition time spent bowling; early cricket specialisation or diversification; quantity of organised practice and competition in other sports across defined age periods.
3. Cricket developmental milestones: Highest level of cricket representation within defined age periods; age first selected for each representation level; level of challenge encountered; age of spin bowling specialisation; age became teams' best spin bowler; age thought about becoming professional cricketer; perceived quality of coaching and facilities; injury time across defined age periods.
4. Unstructured cricket activity: Quantity of unorganised cricket play; time spent reading about cricket; time spent watching cricket.

Qualitative Measures. A relatively unstructured interview schedule was designed to obtain a deeper understanding of any quantitative discriminating features relating to the development of elite spin bowlers. Five qualitative questions were included in the interview, to explore key developmental milestones. These questions are noted below:

1. What were your biggest challenges along your pathway to becoming a spin bowler?

2. If applicable, how did you overcome such challenges?
3. What had the single biggest influence on your development as a spin bowler?
4. Was there a significant learning experience / key moment that took place during your development that eventually contributed to the career you had?
5. Is there anything else of significance that we have not touched on that would be helpful in understanding your journey to becoming a (county or international) spin bowler?

All verbatim obtained from the qualitative component of the interview was recorded for transcription and coding purposes, in preparation for analysis.

Procedure

After the study received institutional ethics approval, participants were recruited by the ECB's National Lead Spin Bowling Coach. Once participants had agreed to take part, and had provided written informed consent, they were interviewed using the specified interview schedule. All interviews were conducted by the same experimenter, and were asked the quantitative set of questions first, immediately proceeded by the qualitative section. Each interview lasted approximately 2 hours, and were recorded to back-up the data. Once all interviews had been completed, the quantitative data collected was subsequently standardised, and analysed using pattern recognition approaches[6], with the primary aim of determining which developmental features discriminate between elite and sub-elite spin bowlers. Transcription of the qualitative data obtained was outsourced to UK Transcription, and was subsequently coded and analysed by the fifth author (who was blind to the quantitative findings), with the primary aim of identifying any discriminating themes between elite and sub-elite spin bowlers.

Analytical Strategy

[6] As pattern recognition analysis had only very recently been applied to the sport science field at the commencement of the PhD, the candidate developed a set of procedural guidelines for its application in the field. The guide was produced in collaboration with Professor Lew Hardy, and Professor Lucy Kuncheva, who is a world leader in the field; this document can be found in Appendix 1.

Quantitative Design. Previous talent identification research has often identified isolated features of theoretical interest, and subsequently examined statistical differences by way of attaching importance (e.g., Ericsson et al., 1993). Improving upon the use of such (limited) traditional statistical procedures, the present study adopted pattern recognition analysis, by way of increasing predictive power. Pattern recognition analysis has been developed in bioinformatics to solve the problem of classifying objects on the basis of features that they possess (*see*, for example, Duda, Hart, & Stork, 2001). The essence of this solution is that modern computational power is used to analyse a large number of features and find which features best distinguish between two different classes of objects. In the present case, the features are the characteristics that have been recorded from our sample of elite and sub-elite spin bowlers, and these two groups constitute the classes of objects that we want to be able to identify. In very simple terms the computer programmes that run these analyses can select features (characteristics), and classify which classes (groups) objects (spin bowlers) belong to, using a number of different criteria. Unlike discriminant function analysis, which predicts group membership based on linear functions of a set of variables (features), pattern recognition analysis is performed on a machine learning workbench that uses algorithms and data pre-processing tools, with non-linear predictive modelling and data analysis capabilities (WEKA; Witten, Frank, & Hall, 2011). Results produced from pattern recognition analyses reflect multiple and complex interactions which take place between the features, not the sum of a number of "main effects" as in more traditional approaches. A 3-staged pattern recognition approach was adopted in the present study, a protocol advocated by Jones, Hardy, and Kuncheva (2017) (*see* Appendix 1) and Güllich et al. (2019): Feature Selection; Initial Classification; Final Classification – Recursive Feature Elimination (these staged approaches are briefly described below).

The present dataset is termed "wide" because there are far more features than there are objects. Therefore, robust *feature selection* protocols should be applied to prevent spurious results. There are a vast number of different procedures that can be used for feature selection (Dash & Liu, 1997; Liu & Motoda, 2007; Guyon, 2003; Kohavi & John, 2011; Larran & Saeys, 2007). Four were used in the present analyses: Support Vector Machine (SVM; Burges, 1998); Relief-F (Kira & Rendall, 1992a); Fast Correlation Based Filter (FCBF; Yu & Liu, 2003); and Correlation Attribute Evaluation (Hall, 1999). Each of these procedures uses very different criteria to select features. However, the most important points for the reader to note, are that the four procedures used are well established, and the selection of features using numerous selection methods is a conservative approach which helps prevent features being awarded high importance due to chance (Visa, Ramsay, Ralescu, & van der Knaap, 2011). The more times that a feature is selected by different procedures, the greater the confidence that can be placed in the predictive power of the feature. As such, features selected by more than one procedure are selected for initial classification in the present study, having been identified as possessing the greatest predictive power.

In order to evaluate the cumulative predictive power of the feature subset selected, four different classifiers were adopted for the *initial classification* of the features. Like feature selection procedures, there are many different classifiers, and like feature selection, one can place greater confidence in results that can be replicated across different classification procedures. All classifiers were applied using the default parameter settings in Weka. The classifiers used were: the SVM classifier (as used in the feature selection; Burges, 1998); Multilayer Perceptron classifier (MLP; Bishop, 1995); Naïve Bayes classifier (NB; Hand & Yu, 2001); and Nearest Neighbour classifier (Lazy learner, IB1; Duda et al., 2001).

To account for the fact that we are working with a wide dataset, we chose the leave-one-out (LOO) cross validation protocol for feature-selection and classification analyses. This protocol removes one participant prior to allowing the classifier to learn how to discriminate between the two groups and then tests the classifier on the participant removed. This cross-validation process is carried out 28 times in total, with each of the participants used once as the 'testing data' (twenty-eight-fold cross-validation). This training-and-testing protocol reduces the risk of overfitting and thereby gives a more realistic prediction of the classifier's performance on unseen data (the generalisation performance).

Final Classification. Next, the Recursive Feature Elimination method (RFE) (Guyon, Weston, Barnhill, & Vapnick, 2002) was employed, using the SVM classifier, as this has been adopted as the state-of-the-art standard for feature selection (Bolon, 2015), especially in the area of bioinformatics (Zhang et al., 2006; Zhou & Tuck, 2007). RFE identifies the subset of features that predicts the class labels with higher classification accuracy, allowing us to provide the user with the optimal solution for a given dataset.

This is the first time that pattern recognition analysis has been used in cricket talent research, allowing a novel concurrent investigation of the multifaceted and holistic nature of expertise development. Following the collation of the interview data, a total of 93 features were left to be analysed. The results produced from the aforementioned 3-stage process are outlined in the Results section.

Qualitative Design. The ontological position adopted by the researchers was a critical realism position (Braun & Clarke, 2013), and the epistemological position taken was the pragmatic paradigm (Doyle, Brady, & Byrne, 2016). The qualitative analysis was based on a combination of traditional inductive content analysis (Weber, 1985) and the principles of inductive grounded theory analysis (Glaser & Strauss, 1967). The transcriptions were analysed using QSR International's NVivo 10 qualitative data analysis software (NVivo qualitative data analysis software, 2012). For themes to be classified as discriminating between the two groups of spin bowlers, they needed to be largely represented by at least four participants from the elite or sub-elite groups. Results were considered commonalities when the number of quotes were similarly represented across the two groups, with specifically no more than a difference of two participants between the groups. Lastly, in instances where there was an insufficient number of participants from either group of spin bowlers represented in a theme (for it to constitute a discriminator or a commonality), we considered there to be no clear consensus, and regarded these themes as additional answers.

Results

Quantitative Findings: Pattern Recognition Analyses

Feature Selection. The top 20 features for the 4 feature selection methods are numbered in Table 1, ranked from best to worst. Features which are selected by more than one feature selection method are colour coded.

Table 1. Top 20 feature rankings across the 4 feature selection methods

Rank	SVM	Relief-F	CFS	CAE
1	30	1	30	30
2	73	71	56	48
3	56	57	37	57
4	54	58	1	43
5	48	67	57	56
6	1	26	49	1
7	57	24	48	41
8	41	43	42	45
9	62	30		31
10	25	68		37
11	67	6		59
12	38	34		62
13	37	66		25
14	55	75		68
15	22	76		7
16	50	33		32
17	53	64		54
18	87	9		76
19	43	73		74
20	93	4		24

Note. Labels of features selected only once: **4** – No. of older siblings; **6** – Primary school principle place for sport practice?; **7** - Primary school a designated sport school?; **9** – Went to higher education?; **22** - Organised practice hours intensity up to First XI debut; **26** - Proportion of spin bowling-specific practice up to age 14; **31** – Number of cricket competition hours up to age 14; **32** - Cricket competition hours intensity up to age 14; **33** - Number of cricket competition hours up to age 17; **34** – Cricket competition hours intensity up to age 17; **38** – Cricket competition hours intensity up to age of international debut; **42 –** Age of first cricket involvement playing family/friends; **45** - Age first thought about becoming professional cricketer; **49** – Age of specialisation in cricket; **50** – Age of specialisation in spin bowling; **53** - Age of first close relationship with a coach; **55** – Age first selected for ECB training squad; **58** - Highest level cricket competition by age 20; **59** – Age of senior club cricket debut; **64** – Age of senior 2nd XI cricket debut; **66** – Level of Challenge senior 2nd XI cricket debut; **71** – Level of challenge senior 1st XI cricket debut; **74** – Age became regular senior First XI cricketer; **75** - Age regular involvement in any unstructured sport; **87** - Unsupervised cricket practice hours intensity up to age 17; **93** - Unsupervised cricket practice hours intensity up to age of international debut.

On viewing the Table 1, it is apparent that a total of 36 out of 93 features appear in the top 20 rankings cumulatively across the 4 selection methods. In the present analyses, features were selected if they were ranked in the top 20 discriminatory features by at least two out of the four feature selection methods used, which led to the initial retention of 16 features, shown in Table 2.

Table 2. The 16 selected features common across at least 2 of the feature selection methods

Feature Number	Feature Labels
1	Birth Quarter
24	Age of First Organised Spin Bowling-Specific Practice
25	Proportion of Spin Bowling-Specific Practice up to Age 14
30	Mean Overs Bowled up to First XI Debut
37	Cricket Competition Hours up to Age of Senior International Debut
41	Age of First Regular Involvement in Cricket
43	Age of First Involvement in Unsupervised Practice
48	Age Decision Made to Become Professional Cricketer
54	Age First Joined a County Cricket Academy
56	Highest Level of Cricket Competition by Age 14
57	Highest Level of Cricket Competition by Age 17
62	Years Taken to Achieve First Significant Perf. Snr Club Cricket
67	Years Taken to Achieve First Significant Performance In 2nd XI CC
68	Years Taken to Become Best Spinner in Second XI CC
73	Years Taken to Become Best Spinner in First XI CC
76	Cricket Play Hours up to Age 14

Initial Classification.

The initial classification accuracy (percentage of correctly classified players) of the four different classifiers for the dataset of 28 players described by the 16 selected features was as follows:

- Support Vector Machine (SVM) Classifier: 78.6%
- Multilayer Perceptron (MLP) Classifier: 82.1%
- Naïve Bayes Classifier: 85.7%
- Nearest Neighbour (Lazy learner, IB1) Classifier: 85.7%

Initial classification revealed that all 4 classifiers discriminated between the two classes with accuracies greater than that expected by chance (50%). Further analysis of the dataset was used to return a subset of features with the *greatest* ability to discriminate between elite and-sub elite spin bowlers.

Final Classification – Recursive Feature Elimination (RFE). The 16 feature scores returned by SVM were ranked, and the feature with the lowest score was removed. An SVM was trained and tested again using the LOO protocol. The *new* 15 feature scores were ranked, and the feature with the lowest score was removed. This process was repeated until classification accuracy no longer improved, upon removing the next lowest weighted feature, meaning that there was no statistical basis for further removal of features. This led to the removal of 4 features, and the retention of a predictive model containing 12 features (*see* Table 3).

Table 3. Individual SVM feature weightings before and after features with low weightings were removed and the protocol was re-run

Feature	Weighting Before Extraction	Weightings After Extraction
Highest Level of Cricket Representation by Age 14	+ .7127	+ 1.4684
Age First Joined a CC Academy/Junior Representative CC	+ 1.1889	+ 1.2423
Years Taken to Become Best Spin Bowler in First XI CC	- 1.1137	- 1.1445
Competition Overs Bowled up to County First XI debut	+ 1.1857	+ 1.1258
Age Decision Made to Become Professional Cricketer	- .8822	- 1.0851
Cricket Competition Hours up to England Snr Debut	+ .8138	+ .8796
Age of First Involvement in Unsupervised Practice	- .8554	- .7966
Years Taken to Achieve Sig Performance in Snr Club Cricket	- .621	- .8769
Age of First Regular Involvement in Cricket	- .714	- .8317
Birth Quarter	+ .9816	+ .8206
Spin Specific Practice up to Age 14	+ .6389	+ .6964
Years Taken to Achieve Sig Performance in Second XI CC	- .6652	- .6541
Age of First Organised Spin Bowling-Specific Practice*	- .2745	-
Highest Level of Cricket Representation by Age 17*	+ .5285	-
Years Taken to Become Best Spin Bowler in 2nd XI CC*	- .3993	-
Cricket Play Hours up to Age 14*	+ .2842	-

Note. Number of Instances = 28. Positively weighted features reflect a positive relationship with the elite class - where a *higher* number is associated with elite group membership. Negatively weighted features reflect a negative relationship with the elite class - where a *lower* number is associated with elite group membership. CC = County Cricket; Jnr = Junior; Snr = Senior. * Removed due to low importance weightings.

The final classification accuracy (percentage of correctly classified players) of the four classifiers for the dataset of 28 players described by the 12 features was as follows:

- Support Vector Machine (SVM) Classifier: 92.9%
- Multilayer Perceptron (MLP) Classifier: 89.3%
- Naïve Bayes Classifier: 82.1%
- Nearest Neighbour (Lazy learner, IB1) Classifier: 78.6%

Quantitative Findings: Summary

The final classification analysis highlights that the SVM classifier produces the greatest accuracy (92.9%), and also observes the largest increase in classification accuracy from initial classification to final classification (+14.4%). Consequently, we can conclude that this classifier discriminates between the elite and sub-elite with *very good* accuracy, and supports the findings of Pfeiffer and Hohmann. (2012) who conclude that pattern recognition approaches are excellent tools to predict competitive performance categories using developmental features. The analysis confirmed that the predictive model containing the following developmental features discriminated between elite and sub-elite spin bowlers with the greatest classification accuracy: highest level of cricket representation by age 14; age first joined a county cricket academy; years taken to become best spin bowler in First XI County cricket; competition overs bowled up to First XI County debut; age decision made to become professional cricketer; years taken to achieve significant performance in senior club cricket; cricket competition hours up to senior international debut; age of first involvement in unsupervised cricket practice; age of first regular involvement in cricket; birth quarter; years taken to achieve a significant performance in Second XI county cricket; and proportion of spin bowling-specific practice up to age 14. The 12 features discriminate as a combination, and as such, should be interpreted as a holistic profile. The stereotypical profiles of the elite and sub-elite are visualised in Figure 1. The descriptive statistics of the features are shown in Table 4.

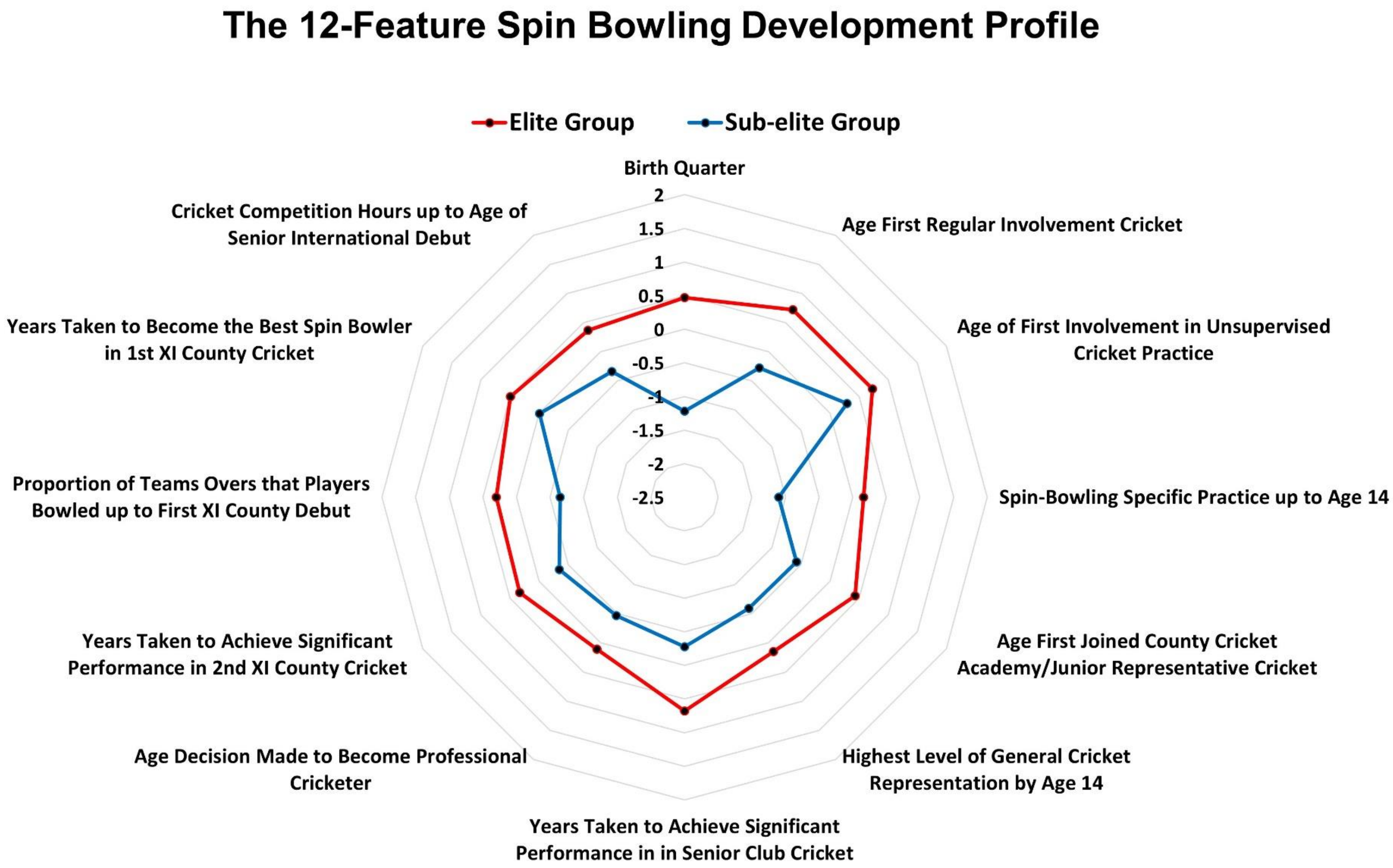


Figure 1. The 12 developmental features that discriminate between elite and sub-elite spin bowlers.

Note. Data points reflect the standardised median values for each expertise class. A higher number is associated with the elite group. membership. The values of negatively weighted features (outlined in Table 3) are reversed, in order to present the discrimination of the elite/sub-elite development profiles through visual means.

Table 4. Unstandardised descriptive statistics of the 12 developmental features that discriminate between elite and sub-elite spin bowlers.

#	Feature	Elite Group				Sub-Elite Group			
		Mean	**Median**	**Minimum**	**Maximum**	**Mean**	**Median**	**Minimum**	**Maximum**
1	Highest Level Cricket Representation by Age 14*	5	4	1	6	4	3	2	4
2	Age First Joined County Cricket Academy/ Junior Representative Cricket	13.60	14	8	17	12.23	11	8	17
3	Years Taken to Become Best Spin Bowler in First XI County Cricket	1.33	4	0	14	6.87	6	1	17
4	Mean Proportion of Competition Overs Bowled up to First XI County Debut (%)	29.40	28	12	55	21	20	16	27
5	Age Decision Made to Become Professional Cricketer	15.60	17	7	19	17.96	18	15	22
6	Cricket Competition Hours up to England Debut	11,016	11,340	4,524	26,718	11,382	8,317	6,140	11,382
7	Age of First Involvement in Unsupervised Cricket Practice	8.27	7	5	14.50	10.92	10.50	6	20
8	Years Taken to Achieve Significant Performance in Senior Club Cricket	0.47	0	0	1.5	1.04	1	0	5
9	Age of First Regular Involvement in Cricket	7.37	6	2	12	9.23	9	4	14
10	Birth Quarter	2.80	3	1	4	2.00	1	1	4
11	Spin Specific Practice up to Age 14 (%)	51.47	50	0	100	30.77	0	0	90
12	Years Taken to Achieve Significant Performance in Second XI County Cricket	1.33	1	0	4	1.77	2	0	5

Note. *Cricket Representation Levels: 1 = Junior Club Cricket, 2 = Senior Club Cricket, 3 = Junior County Cricket, 4 = Regional Cricket, 5 = 2nd XI County Cricket, 6 = International Youth, 7 = First XI County Cricket

An important disclaimer must be made here. The classification accuracy which we report above for the set of 16 features, and even more so for the set of 12 features may be slightly optimistically biased. The reason is that because Weka's protocol for feature selection (LOO or not) is followed by another round of using the same data in order to train and test the classifier (LOO). In other words, the object set aside for testing has been "seen" during the training stage, when feature selection was carried out; the so-called "peeking" (Kuncheva, 2014; Smialowski, Frishman, & Kramer, 2010). The effect of this peeking is indirect and ignored in many studies. Nonetheless, one cannot make the claim that the classification accuracy on unseen data will match the one achieved for this dataset, until this has been directly tested, as part of a model validation (as performed below).

Confirmatory Model Testing

The 12-feature model successfully discriminates between elite and sub-elite players with very good accuracy; the next required step was to test the model's ability to generalise (and thus predict) unseen datasets, i.e., spin bowlers who were not included in the original analysis. This follows the training-and-testing protocol previously adopted during feature selection and classification. To do this, we utilised the interview data of 5 additional spin bowlers, 3 of whom met the were elite (international cricketers), having represented England, Pakistan and New Zealand international cricket boards respectively, and 2 of whom were English sub-elite (professional county) spin bowlers. The selected classifier (SVM) predicted the true expertise class of elite and sub-elite spin bowlers with 100% accuracy, lending support to the model's generalisability on unseen data. A future prospective replication study would allow further scrutiny of the model's external validity.

Qualitative Findings: Content Analysis

The analysis comprised three stages. The first two stages were conducted independently by the fifth author, whereas the first, second and fifth author conducted the final triangulation stage. During the first stage, common themes were categorised as lower-order. The lower order themes were subsequently grouped into higher–order themes, until all similarities between themes were saturated and no further higher order themes could be determined. The final stage involved a triangulation process, to verify, validate and reduce any systematic bias during the analysis. This involved a discussion that challenged the initial interpretation of the data, and disagreements were resolved by reference to the original transcripts and further discussion, until full consensus was reached. Discussion of the extensive verbatim quotes that comprised each higher order theme led to the identification of five themes discriminating between the elite and sub-elite, along with six commonalities.

Qualitative Discriminating Findings: Summary

The discriminating themes indicated that sub-elite spin bowlers were more likely to have experienced difficulties in overcoming their development challenges; these were attributed to nervousness about performance, a fear of failure, feeling unequipped to cope with high-level expectations, and a lack of support from others. Whereas, elite spin bowlers were more likely to overcome such challenges they faced during their development by deliberately engaging in hard work and training, which discriminated the elite (*see* Supplementary Information for extended qualitative findings). The complementary nature of the qualitative and quantitative findings allowed for the conceptualisation of four developmental themes, as discussed below.

Discussion

The present study sought to identify the developmental features that differentiate elite and sub-elite spin bowlers. We conducted a detailed examination of development within the sport of cricket, and adopted distinct criteria to discriminate between levels of spin bowling expertise; spin bowlers who had competed at senior international level (elite) and spin bowlers who had been professional cricketers, but only at the domestic First-Class county level (sub-elite). The mixed method approach adopted, which included the application of pattern recognition analyses, addressed a number of methodological limitations of previous expertise, allowing the authors to adopt a holistic approach to concurrently investigate the multifaceted and complex nature of expertise. In the authors' opinion, this novel approach is a strength of the study. Furthermore, the advanced pattern recognition techniques adopted in the present paper lend themselves to future research attempting to identify precursors of expertise across different sports.

The 12-feature classification model produced from the quantitative analyses discriminated between the elite and sub-elite classes with very good accuracy. Subsequent validation analysis of the final 12-feature model, using an unseen dataset of five players revealed a perfect (100%) classification fit of this testing data. Results of this validation analysis highlight that the 12-feature model can be generalised to spin bowlers outside of the original sample, as well as to spin bowlers worldwide. The external validity demonstrated in the present study may prompt international cricket boards to examine their own development structures, by way of maximising the development of spin bowlers and other cricket disciplines.

The qualitative component of the study added depth to our understanding of the features that discriminate between the elite and sub-elite groups identified in the quantitative analyses, and produced an additional five discriminating themes. Six commonalities between the elite and sub-elite were also identified, alongside the additional answers, and are reported in full within the Supplementary Information.

In order to facilitate discussion of the findings in relation to existing theoretical framework, and the temporal sequence of spin bowler development in England and Wales, the 12-feature model was subdivided across four areas of development (Early Development; Pathway Milestones; Domain-Specific Activity; Pathway Performance Indicators). This framework allowed the emergent themes derived from the qualitative findings to be integrated into the discussion

Early Development

Initial cricket development is unsurprisingly linked to birth quarter and age of regular exposure to cricket (Barney, 2015). However, our findings suggest that the interplay between birth quarter and age of exposure to cricket may not be linear, as previously suggested (for a review *see* Cobley et al., 2009). Firstly, the findings revealed that elite spin bowlers were born later in the year than their sub-elite counterparts, adding further support to existing cricket research demonstrating differential RAEs, contingent on expertise level and discipline (Barney, 2015; Jones et al., 2018). McCarthy et al. (2016) similarly reported that a significantly greater proportion of graduate players from the ECB's talent pathway who become senior international players were born later in the year (Q4 RAE). Many of the elite spin bowlers in the present study were attached to a different discipline during their formative years**,** and RAE bias is confounded by the significant weighting placed on physical requirements for some disciplines, e.g., pace bowling. Furthermore, de-selection due to physical maturation bias is suggested to result in a resurgence of young players with greater psychological resilience re-entering youth sport programmes (Lewis et al., 2015). Qualitative analysis emphasized the need for spin bowlers to be resilient in the face of adversity, as was explained by an elite spin bowler; "You've got to be resilient, you've got to be tough and you've got to be strong to keep bouncing back" (P21). Furthermore, becoming a spin bowler provides opportunity for relatively younger players to remain viable and excel in cricket, due to the emphasis placed on technique, rather than physical development (P. Such, ECB National Lead Spin Bowling Coach, personal communication, 27th September, 2016).

Our second finding highlighted that elite spin bowlers became regularly involved in cricket earlier than sub-elite bowlers. The benefits of early participation within a sport are denoted by the 'sampling stage' of the Development Model of Sport Participation (Cotè et al., 2007). This stage denotes the benefits of early sport participation, through engagement in playful activities which harness learning through trial and error, and develop young players' intrinsic motivation towards a sport. Considering the fundamental differences that exist between the cricket disciplines (Jones et al., 2018), coupled with the current knowledge that neither group of spin bowlers typically specialised in the spin bowling discipline until early in their teenage years (M_{age} = age 14), we can infer that the early cricket experiences of both groups of spin bowlers were somewhat diverse. The present finding suggests that elite spin bowlers may have specifically benefited from the earlier (regular) engagement in these diverse sport experiences. Earlier engagement is shown to develop intrinsic motivation towards a sport; promoting self-regulation, and an internal drive to succeed (Cope, Bailey, & Pearce, 2013). Furthermore, self-regulation is a positive predictor of elite group membership in sport (Bartulovic, Young, & Baker, 2017). Thus, a greater drive to succeed could mean that prospective elite spin bowlers are more likely to undertake greater volumes of practice, contributing to the development of spin bowling expertise (McCardle, Young, & Baker, 2017; Rees et al., 2016). The benefits of these earlier diverse sport experiences appear partly indicative of the early engagement hypothesis, which suggests that prolonged exposure to play and practice activities in a sport, aided by early sport specialisation, facilitates the subsequent expertise development in the field (Ford et al., 2009); however, there is no evidence of early sport specialisation in the present study. Moreover, elite spin bowlers' earlier engagement in diverse cricket experiences was likely important in developing the required fundamental motor skills for cricket, and spin bowling technique specifically, to perform at the highest level (Goodway & Robinson, 2015).

Thirdly, elite spin bowlers also engaged in unsupervised practice sessions earlier than the sub-elite, suggesting an earlier shift in focus from regular (recreational) cricket participation, to targeted unsupervised practice. The benefits of early sampling are now likely reflected in the behaviour of the (prospective) elite spin bowlers, who appear to be acting on their developing inner drive for the sport (Cope et al., 2013; Cotè et al., 2007), and like extends the benefits of the early engagement hypothesis (Ford et al., 2009). The present finding also demonstrates that prospective elite spin bowlers' actions *outside* of competition are in fact distinguishable from prospective sub-elite bowlers during the earliest stages of development. Elite bowlers' earlier engagement in unsupervised practice is likely an additional indicator of self-regulation, as they begin to take control of their behaviour, in pursuance of their developmental goals (McCardle et al., 2017). Continued development and progression of self-regulated learners could have a positive bearing on the success of the ECB talent pathway. The lack of observable performance indicators during the earliest stages of development makes the early identification of talent difficult, especially for sport officials who place primary emphasis on current performance level. In fact, the present findings illustrate that these formative experiences are likely catalysts for the subsequent development of performance, as spin bowlers evolve.

Pathway Milestones

Analysis revealed that elite spin bowlers joined a county cricket academy later than the sub-elite, but made the decision to become professional cricketers earlier. The later entry of elite bowlers into an academy is mirrored in the developmental trajectories of Olympic athletes (Hardy et al., 2013; Rees et al., 2016), and may be the result of an overrepresentation of relatively older and physically mature players in age group cricket (Barney, 2015). This early bias likely affects spin bowlers who transition from a different discipline, due to the distinct differences between spin bowling skill demands, and other disciplines. Consequently, elite bowlers may not have demonstrated sufficient spin bowling potential in performances early in their development, to warrant earlier selection into an academy.

The impact of elite bowlers' early participation in cricket may have influenced the timing of their decision to become professional, as early intrinsically rewarding experiences has been proposed to kindle players' inherent attachment towards a sport (Cotè et al., 2007). However, elite athletes have been shown to possess greater levels of extrinsic motivation and lower levels of intrinsic motivation than their sub-elite counterparts (Fortier, Vallerand, Briere, & Provencher, 1995). Whilst there is ambiguity surrounding *what* motivates young players to become elite, the present findings, along with previous research (Rees et al., 2016), suggest that elite performers may possess greater inner drive than the sub-elite. This is supported by an investigation assessing the discriminant validity of the ECB's scouting process, revealing that inner drive was the only variable (across psychological, physiological, technical and tactical awareness categories) that discriminated between cricketers who remained shortlisted, and those subsequently selected onto the England Development Programme (Barney, 2015). Further, the findings previously discussed relating to 'Early Development' also support the notion that elite spin bowlers may have developed a degree of resilience. That is, through demonstrating exceptional inner drive, to overcome significant obstacles during development, such as the challenges associated with RAE. Indeed, the motivational benefits of the elite's earlier participation in cricket may prepare them for the challenges ahead, kindling an earlier desire to become professional (Cotè et al., 2007). The drive to succeed was evidenced further by the elite in the qualitative findings, whereby data indicated that elite spin bowlers were more likely to have overcome the challenges faced during development with less difficulty than their sub-elite counterparts, often citing failure as their driver for success: "I think, not getting selected, just created the hunger more for me. Like, failing" (P7). Whereas, the sub-elite group identified "fear of failure" (P23), as one of the biggest difficulties that they endured during development.

Domain-Specific Activity

Despite there being no difference between elite and sub-elite's quantitiy of organised practice hours, elite spin bowlers undertook a greater proportion of orgainised spin bowling-specific practice. Whilst the elite's greater quantity of spin bowling-specific practice is consistent with the theory of deliberate practice, where an abundance of domain-specific practice is reported to lead to the development of expertise, it does not support the 10,000 hours benchmark (Ericsson et al., 1993). In fact, the total cricket practice hours (organised and unorganised) within the present study was notably under 10,000 hours for both the elite (M_{hours} = 5,697, *SD* = 2,285) and sub-elite (M_{hours} = 5,561, *SD* = 3,262) groups, up to the age at which they became elite, and is consistent with a study of elite Australian spin bowlers (Mann, 2014). That said, the present finding mirrors the conclusions of recent studies demonstrating that high volumes of domain-specific practice increase the probability of developing expertise (*see* Rees et al., 2016). This was supported by the majority of elite spin bowlers who explained that they overcame the selection challenges by "working hard, practising hard" (P16; P20), coupled with the clear distinction in the elite and sub-elite's proportion of spin bowling-specific practice. Furthermore, accumulation of domain-specific practice during formative years, allows for trial and error, and subsequent acquisition of fundamental spin bowling movements, enabling translation into competition concurrently (Pinder et al., 2011; Rothwell et al., 2017).

The elite had also bowled a larger proportion of their teams' overs up to the age of their First XI County debut. The frequency of competition overs bowled may not serve to only indicate current performance level, but is also likely a hallmark of potential. The inherent difficulty facing developing spin bowlers in achieving a repeatable action demands resilience; further resilience is required for players challenged by RAE, and met with a "lack of knowledge from captains…and coaches" (P23) and unresponsive "flat pitches" (P17), all of which are likely to impact on the selection of spin bowlers (Mann, 2014). The findings appear to suggest that it is those resilient spin bowlers who are able to overcome such challenges, that are likely trusted to bowl, and subsequently go on to become elite (McCarthy et al., 2016). Bowling a substantial amount of competition overs by the age of their First XI debut appears paramount for developing spin bowlers, particularly given how the time constraints associated with the senior cricket competition schedule often reduces time available to practice, meaning that recurring flaws identified must often be addressed 'on the job' during competition (A. Strauss, former ECB Director of Cricket, Personal Communication, April 11, 2016).

In addition to the greater proportion of competition overs bowled before their First XI County debut, the elite had also accumulated a greater quantity of cricket competition hours up to the age of their international debut, compared to the sub-elite[7]. This finding is likely partly a bi-product of the elite's early exposure to additional higher-level competition, and more time spent bowling during competition. Upon reaching First XI County Cricket, the elite are selected for competition more regularly, likely owing to their developed competencies, and a strong track record. In fact, the most marked difference in competition experience exists once spin bowlers reach the First XI County game. As such, it appears paramount that spin bowlers consistently demonstrate the successful transfer of spin bowling-specific practice into competition overs, and cope with the psychological demands of spin bowling, by the time they reach the pinnacle of the domestic county game, based on the findings of the present study. Since the sub-elite had experienced less spin bowling-specific practice, less competition overs, and less general competition time during their development, it can be inferred that the sub-elite were not equipped to deal with the concurrent technical and psychological demands of competition. Consequently, the sub-elite's development could have been limited by inferior skill level and/or an inability to transfer their skillsets to competition on a consistent basis.

[7] The average age of the elite's international debut was calculated, and then used to determine the quantity of competition hours that the sub-elite had experienced by the age of this milestone.

Despite the revelation that the elite had undertaken significantly more spin bowling-specific practice, it is important to note that age of specialisation in the sport of cricket (elite: M_{age} = 16.73, sub-elite: M_{age} = 17.61) and spin bowling as a discipline (elite: M_{age} = 14.07, sub-elite: M_{age} = 13.62) were also explored in the present study, but did not discriminate between elite and sub-elite spin bowlers. Consequently, the present finding is not indicative of the pre-existing positive and linear relationship between early specialisation (at neither an inter nor intra-sport level), and volume of domain-specific practice (for a review *see* Rees et al., 2016). In fact, in the case of both elite and sub-elite spin bowlers, the ages reported in the present study appear most indicative of later, *rather than* earlier, sport specialisation, which is contrary to data reported across a number of historic studies denoting the benefits of early sport specialisation (e.g., Ericsson et al., 1993; Ward et al., 2004). Clearly, there is a need for future research to measure both inter and intra-sport specialisation as separate constructs to advance understanding of the complexities of specialisation.

The present findings support previous research outlining the benefits of early diversification, facilitated by early engagement in sport (Güllich, 2014; Rees et al., 2016). Furthermore, it appears that the spin bowlers sampled in the present study benefited from early diversification *within* the sport of cricket, *coupled with* (domain-specific) spin bowling practice. That is, the elite's early investment in prolonged spin bowling-specific practice, whilst simultaneously developing wider skills from a diversified cricket development, appears an important foundation in their pursuance of becoming elite (Mann, 2014). The development of a wider skill repertoire, enhanced by a diversified cricket development is likely to lead to a roundedness that makes spin bowlers viable acquisitions for academies, subsequently maximising one's chances of becoming an elite spin bowler (Mann, 2014). Furthermore, several sub-elite bowlers highlighted that being a 'one-dimensional cricketer' had often caused them to be overlooked for selection, during their development; "I didn't bat and I was a really average fielder, so I was either bowling well or I wasn't in the team" (P30). Specifically, the perceptual benefits of prior engagement in batting may assist spin bowlers in attempting to deceive batsmen, resulting from a form of self-modelling, (Zetou, Kourtesis, Michalopoulou, & Kioumourtzoglou, 2009). Further, given that conditions in England and Wales may not always be receptive to spin bowling, multidiscipline spin bowlers who also demonstrate prowess as batters, are likely to be favoured during selection. Similarly, a previous attachment to pace bowling may also assist spin bowlers, in developing a foundational strong physique, and enhancing their physical ability to produce a repeatable action in the long-term as a result (Such et al., 2012).

Pathway Performance Indicators

Elite spin bowlers had competed at a higher level of cricket representation than the sub-elite, up to the age of 14; only prospective elite players had competed at the highest of levels of competition (international youth cricket) by age 14. The most parsimonious explanation for this finding, is that the highest potential players demonstrate ability early, and progress to higher forms of the game. Whilst the finding does coincide with a statement made by an elite spin bowler during the interview: "When I was 14, I was playing the top men's league, first team with the club" (P1), the bowler also went on to voice his concerns about youth players in England and Wales competing at lower levels of competition, "A lot of guys now are having to play school's cricket, and then suddenly get dropped in the deep" (P1). This would suggest that youth spin bowlers who are confined to school team representation, may face substantial difficulty when progressing to higher levels in future, owing to the marked difference in competition standards during early in development. However, a note of caution also exists, owing to the wide range of representation levels shown across both expertise groups by age 14, meaning that prospective elite spin bowlers could conceivably come from a diverse playing background at this age.

Superior adaptability to new environments is likely an important attribute in prospective elite spin bowlers, representing 3 of the 12 discriminating features, and may wish to be considered an important criterion for cricket selection, e.g., in making the transition from junior to senior cricket (Barney, 2015). Elite spin bowlers achieved an earlier first significant performance in both senior club cricket and 2nd XI senior county cricket, compared to the sub-elite. These elite spin bowlers appear to have the skills to cope with the increase in physical, psychological, and technical demands at senior level, having previously been exposed to the highest level of competition from an early age. They also likely demonstrated resilience in successfully bridging the gap between junior and senior cricket (Jones et al., 2018). This finding extends previous research highlighting that the ability to adapt to senior (2nd XI) cricket, by taking wickets soon after debut, predicts subsequent performance at international level (Barney, 2015).

The elite's superior adaptability is further emphasized upon reaching the pinnacle of domestic cricket (First XI County Cricket), where adaption becomes more gradual; elite spin bowlers become the best spin bowlers in their respective teams in fewer years than the sub-elite. There was an acknowledgement of the benefit of such troughs in development from one elite spin bowler, who explained "Sometimes you would get there and all of a sudden your progress would stop, and you needed to play at that level for a while before you actually started to move up again" (P19). This finding is consistent with Barney (2015) who concluded that bowlers need the experience of First XI County Cricket to develop technical skills before performing in international cricket. Indeed, elite spin bowlers had accumulated a greater number of competition hours experience up to the age of their senior international debut. Here, we suggest that it is those spin bowlers who develop the desired skills quickest that are likely to become (elite) international cricketers. Of course, becoming the best spin bowler in a respective team is contingent on the performance levels of other spin bowlers in the team. For example, one elite spin bowler explained the benefits and drawbacks of being in the shadow of an (already) elite spin bowler during his development: “It was great to play with him, but I got to a stage where I wasn’t playing anywhere near as much cricket as I felt to ought to or would like to do so I moved county” (P20). In light of this, it is likely that a number of aspiring elite spin bowlers go unnoticed by selectors. This is particularly problematic given how the number of spin-bowled overs are declining in the county game (Coyne, 2016). It appears crucial that spin bowlers who have demonstrated consistency and a robustness up to this point, experience regular competition time, which may require a change in county team. Importantly, the present finding also suggests that county cricket *does* offer spin bowlers with the necessary attributes a route to international level, on the condition that they receive sufficient opportunity to demonstrate their prowess (Vaughan, 2015).

Limitations

There are a number of limitations that the critical reader may relate to the present study. Firstly, as with all retrospective research, there is a risk of error in recall. To mitigate this, we drew a comparator sample who were (on average) the same age, also possessing similar standard deviations (*see* Method). Consequently, it was inferred that any recall inaccuracies owing to age would be approximately equal for both groups. Secondly, the 12-feature model was tested on five unseen participants to gain some idea of the model’s potential generalisability. Whilst a five-participant test-set could be construed as being somewhat underpowered to be considered a genuine standalone replication, the training-and-testing protocol adopted by the Leave-One-Out (LOO) protocol during feature selection and classification ensure that the features are continuously tested on each participant independently. Regardless, the present study contained the entire spin bowling sample in England who fitted the specified criteria. It is therefore conceivable that researchers would have to wait approximately 20 years before a comprehensive replication study could be conducted, by which time, the development landscape would have likely changed again. The multiple classification indices used to test the model provide an early indication of the model's generalisability, which, at the very least, is more informative, than not testing the model for 20 years. Lastly, the interpretation attached to the present findings are theoretically driven, reflecting the authors' understanding of contemporary research in their specialist fields of expertise, but are largely speculative because of the descriptive nature of the research design (i.e., we have not explicitly manipulated any variables, but rather used advanced machine learning analysis techniques to classify expertise based on the developmental biographies).

Summary

Prospective elite spin bowlers develop an early passion for cricket, participating both recreationally, and in unsupervised targeted practice from an early age. However, the development trajectory that follows is indicative of a complex, non-linear journey to becoming senior internationals. They appear to keep their playing options open early on, either through choice, or owing to the maturational effects of being relatively younger within their playing cohort, perhaps in an attempt to remain viable and follow their passion for cricket. It takes prospective elite spin bowlers longer to illustrate that they are high potential, before being selected for an organised county academy programme. Fulfilment of potential is likely delayed further by the 'expensive' nature of spin bowling, when considering the sheer number of runs conceded, compared to pace bowling. Therefore, it is conceivable that a significant proportion of prospective elite spin bowlers do not appear as valuable acquisitions for cricket academies until later, once they demonstrate all-round ability. However, whilst both groups tend to specialise in cricket and spin bowling relatively late, crucially, the elite become exposed to more spin bowling-specific practice and competitive experience, compared to their prospective sub-elite counterparts (whom were already attached to a county academy programme). Early performance indicators demonstrate that whilst elite spin bowlers may come from varied competition backgrounds, only prospective senior elite players played at the highest levels by an early age. Furthermore, upon playing at senior levels, elite spin bowlers adapt to club and 2nd XI county formats quicker, thereby demonstrating resilience. This may explain why they bowl a considerable number of their teams' competition overs up to their First XI County Cricket debut. Over a period of years, prospective international players become the best spin bowler in their First XI County team quicker than their sub elite equivalents, before likely coming to the attention of selectors for the senior (elite) international team.

Implementation

The previously discussed pattern of 12 factors that differentiate between the elite and sub elite groups emerged from a total pool of 93 factors. Thus, it was essential that the remaining 81 factors were interpreted (alongside the qualitative data), as being *equally important* or *equally irrelevant* in becoming a sub-elite spin bowler. To better understand the complexities of the feature profiles of both elite and sub-elite spin bowlers, a research working group was formulated, and was overseen by the corresponding author, consisting of five ECB officials whose roles were directly aligned with the talent pathway: Performance Director; Head of Science, Medicine and Innovation, National Talent Pathway Manager; National Lead Spin Bowling Coach; and Player Identification Lead.

There were three steps to the implementation and dissemination phase: The initial stages focused on the quantitative data. Firstly, elite and sub-elite spin bowlers were combined into a single group, where the remaining 81 relevant features were assessed by comparing the pattern of skewness to extant expertise research literature in sport. Bimodally distributed features were removed. This left 33 features that could be regarded as true commonalities from the analyses of the quantitative data. The six commonalities identified between elite and sub-elite bowlers during the qualitative analysis (*see* Supplementary Information) were then disclosed to the working group, alongside the 33 commonalities obtained from the quantitative analyses. Expert opinion was sought in the second stage, to assist with identifying the commonalities that hold equal importance in achieving sub-elite status., leading to the identification of 19 equally important commonalities (Table 5).

Table 5. The 19 commonalities identified by the ECB's research working group as possessing equal importance to the discriminators (in achieving sub-elite status initially).

#	**Commonality Labels**
1	Age of First Organised Cricket Competition *(-)*
2	Number of Organised Sports Played Across Development *(+)*
3	Age Started Spin Bowling in Competition *(-)*
4	Age of Senior Club Cricket Debut *(-)*
5	Physical Size at Age of Senior Club Cricket Debut *(-)*
6	Level of Challenge upon making Senior Club Cricket Debut *(+)*
7	Age Became the Best Spin Bowler in Senior Club Team *(-)*
8	Age of 2nd XI Senior County Cricket Debut *(-)*
9	Physical Size at Age of 2nd XI Senior County Cricket Debut *(-)*
10	Level of Challenge upon making 2nd XI Senior County Cricket Debut *(+)*
11	Age of Specialisation in Cricket *(+)*
12	Age Became the Best Spin Bowler in 2nd XI Senior County Team *(-)*
13	Age of 1st XI Senior County Cricket Debut *(-)*
14	Cricket Competition Hours up to Age of First XI Senior County Debut *(+)*
15	Unsupervised Cricket Practice Hours up to Age of First XI Senior County Debut *(+)*
16	Cricket Play Hours up to Age of First XI Senior County Debut *(+)*
17	Organised Cricket Practice Hours up to Age of First XI Senior County Debut *(+)*
18	Proportion of Spin Bowling-Specific Practice up to First XI Senior County Debut *(+)*
19	Age Became Regular Choice Spin Bowler in First XI Senior County Team *(-)*

Note. Positively weighted features reflect a commonality where a *higher* number is considered as being 'equally important'; negatively weighted features reflect a commonality where a *lower* number is considered as 'being equally important' (directions of weightings are based on the skew statistics and extant literature consensus).

The commonalities are also depicted in Figure 2, alongside the 12 discriminators previously identified. The final stage involved applying the most likely explanation to the collective quantitative and qualitative findings, informed by the expert opinion of the working group, and extant literature. Applied implications were produced by the working group, and converted into recommendations, which were disseminated nationally, targeted at maximising the identification and development of spin bowlers (presented below).

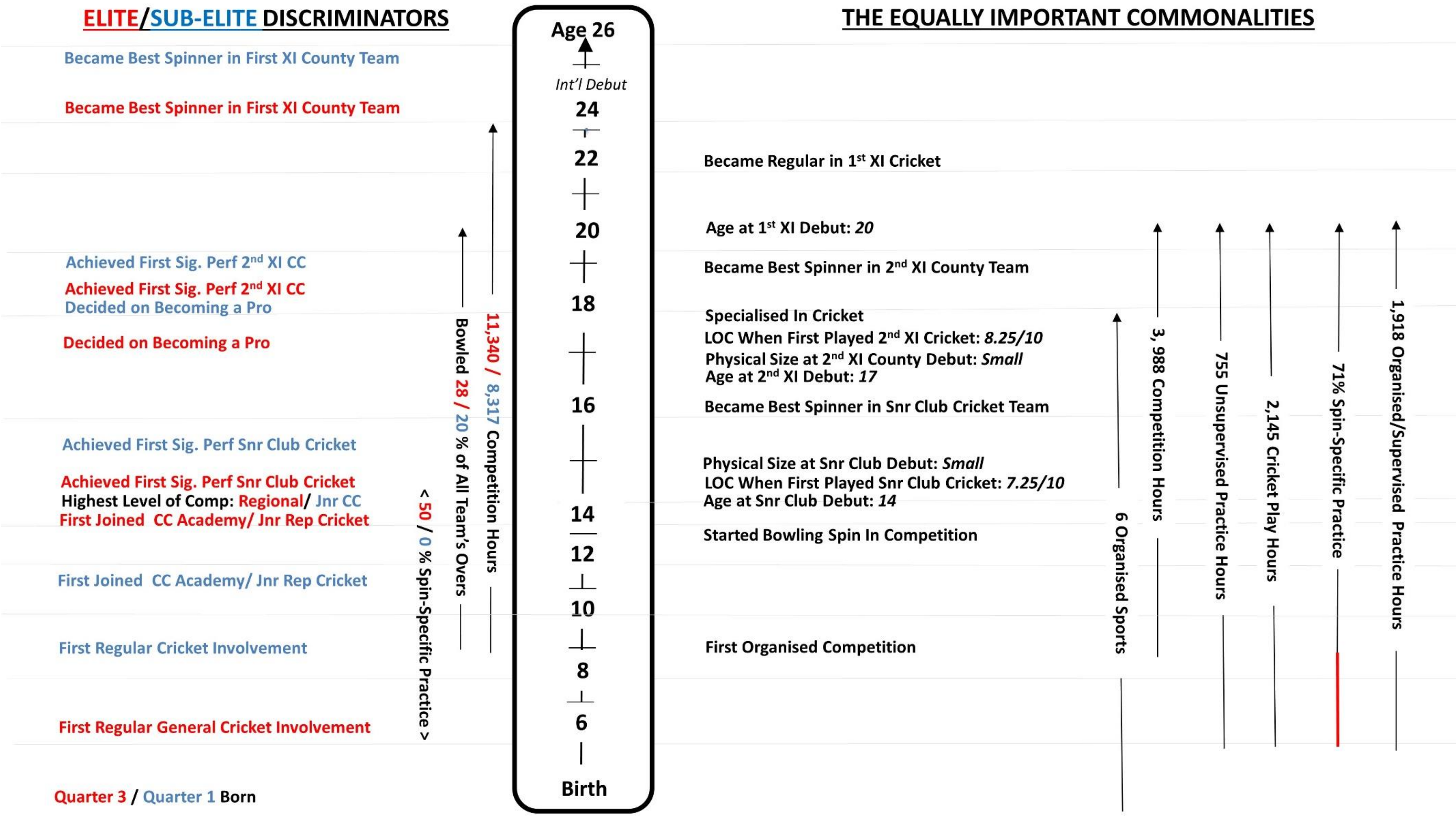


Figure 2. A timeline of the 12 developmental discriminating features between elite and sub-elite spin bowlers (left), and the 19 equally important commonalities identified (right).

Note. Data points reflect the unstandardised median values of each feature

FINDING #1

International spin bowlers appear to demonstrate an early keenness towards cricket during their development, because they:

a) **Became regularly involved in cricket, and spin bowling, from an earlier age than the county spin bowlers** (~ Age 6 vs. Age 9).

b) **Accumulated considerably more spin bowling-specific practice than the county spin bowlers up to the age of 14** (~ 50% vs. 0% of practice sessions).

c) **Decided on pursuing a career in cricket sooner than the county spin bowlers** (~ Age 17 vs. Age 18).

Actions:	**Pre-Pathway (8-12)**	**Early Pathway (U13-15)**	**Mid Pathway (U16-18)**	**Late Pathway (18-21)**
What to do? (*Talent Development Coaching Tips*)	Create opportunities to explore and experiment spinning the ball during practice, making it fun and explorational.	Promote and provide opportunity for prolonged 'spin-specific' practice, alongside multidiscipline practice, during early pathway practice sessions.	Continually encourage and offer opportunity for prolonged 'spin-specific' practice.	
What to look for? (*Talent Identification Tips*)	The emerging 'spin bowling badger' - the kid who has a passion for cricket and spinning the ball.	The flourishing 'spin bowling badger'- the player who takes the bag of balls by himself and practices hard.	The evolved 'spin bowling badger' - the spin bowler who makes cricket, and spin bowling, a priority.	
What to find out? (*Intelligence*)	When did spin bowlers take up cricket/spin bowling, and why?	How much self-directed spin bowling practice do the players do in their spare time? How much 'spin-specific' practice do they do across all environments?	Begin to explore the spin bowlers' cricket aspirations; who does he/she want to be?	Are the spin bowlers' aspirations resilient and enduring; do they 'stick at it'?
Pathway Implications (*Pathway Strategy*)	Instil the principle of spin bowling exploration and experimentation, amongst multidisciplinary cricket practice, into the talent development framework, pathway reviews, coach education resources and coach development programmes.	Coach development and resources for early specialist spin bowling practice.	Use the research to highlight the developmental journeys of high potential (international) spin bowlers to the wider cricket workforce.	

FINDING <u>#2</u>

International spin bowlers achieved their success by overcoming early challenges, specifically they:

(a) **Were younger within their age-groups, and therefore likely physically immature** (~ Q3 Born vs. Q1 Born).
(b) **Were typically selected onto the county talent pathway programme later than the county spin bowlers** (~ Early teens; ages 13-14 vs. Age 11).
(c) **Played to a higher standard of cricket competition up to the age of 14** (**England**: Junior club cricket to England youth; **County**: Senior club to Regional).

<table>
<tr><th>Actions:</th><th>Pre-Pathway (8-12)</th><th>Early Pathway (U13-15)</th><th>Mid Pathway (U16-18)</th><th>Late Pathway</th></tr>
<tr><td>What to do?

(Talent Development Coaching Tips)</td><td>Ability to spin the ball may be hampered by physical immaturity. As such, create opportunities to explore and experiment spinning the ball during practice, making it fun.

Strategies for achieving this may include extended use of smaller balls during development (i.e., 4.75oz or 5oz), and manipulation of surfaces/net manipulation to validate spinning the ball.</td><td colspan="2">Physical immaturity may hamper spin bowlers' ability to spin the ball or land the ball 22-yards during competition. Smaller hand size, associated with physical immaturity, may also prompt spin bowlers to bowl leg spin, rather than finger spin, initially. Long-term spin bowling potential should therefore be considered relative to current stage of maturity, along with a combination of:
1. Snap and energy in the action; evidence of shape in the air and spin off the pitch.
2. The demonstration of perseverance and creativity in practice & competition to 'find a way'.
3. Ability to adapt to new challenges.
4. Resilience to deal with setbacks.

Given this possible later onset of physical maturity in spin bowlers, decision-makers should explore opportunities to play players down age-groups, where selection is restricted due to immaturity.

Maturational differences or injury may cause pace bowlers to transition to spin bowling later in development. Facilitate this transition by offering multiple pathway entry points, and through fostering a spin-friendly environment, providing specialist spin bowling coaching at point of entry.</td><td></td></tr>
<tr><td>What to look for?

(Talent Identification Tips)</td><td></td><td colspan="2">Potential in spin bowling action, regardless of ability to spin the ball (relative to stage of physical maturity).

Perseverance and creativity to stay viable.

Behaviours reflecting adaptability and resilience.</td><td></td></tr>
<tr><td>What to find out?

(Intelligence)</td><td>Is there an underlying reason why the spin bowler(s) are not currently the standout 'talented' players (performances aside)?

Birth quarter & biological maturation status.</td><td>Is there an underlying reason why the spin bowler(s) are not currently the standout 'talented' players (performances aside)?

Birth quarter & biological maturation status.

Do spin bowlers adapt to the competitive challenges, and opportunities of the county pathway, quickly?</td><td></td><td></td></tr>
<tr><td>Pathway Implications

(Pathway Strategy)</td><td></td><td colspan="2">Profiling and monitoring systems. Specialist spin bowling coaching.

Increased emphasis on method and ability to spin the ball when judging spin bowling potential (by way of reducing emphasis placed on youth competition performances solely).

Ensure that an agreed structure exists for 'playing spin bowlers down' age groups.

Multiple pathway entry points.</td><td></td></tr>
</table>

FINDING #3:

International and county spin bowlers typically 'specialised' in cricket, and in spin bowling later, rather than earlier in development (Cricket specialisation ~ Age 16-17; Spin specialisation ~ Age 13-14).

So, our research shows that international spin bowlers did both spin bowling-specific practice *and* multi-dimensional cricket practice to around age 14.

Actions:	Pre-Pathway (8-12)	Early Pathway (U13-15)	Mid Pathway (U16-18)	Late Pathway (18-21)
What to do? (*Talent Development Coaching Tips*)	Provide multi-disciplinary cricket experiences in practice and competition. Encourage multi-sport participation.			
What to look for? (*Talent Identification Tips*)		Prioritisation of spin bowling (*discipline specialisation*).	Prioritisation of cricket (*sport specialisation*).	
What to find out? (*Intelligence*)		Whether spin bowlers are committed to developing their second/third disciplines. Whether spin bowlers are engaged in other complimentary sports/activities.		
Pathway Implications (*Pathway Strategy*)	Multi-sports exposure Multi-discipline cricket exposure			

FINDING #4:

International spin bowlers demonstrated superior adaptability to county spin bowlers, by typically:

a) **Achieving a first significant performance within a year of making their senior club and Second XI county debuts** (i.e., first 3fer, 5fer to 10 wicket haul).
b) **Becoming the best spin bowler in their First XI County team within fewer years.** (typically 4 years following debut).

Actions:	Pre-Pathway (8-12)	Early Pathway (U13-15)	Mid Pathway (U16-18)	Late Pathway (18-21)
What to do? (*Talent Development Coaching Tips*)		Enable as much challenging scenario and performance-specific practice as possible throughout development, to develop adaptability in bowlers.		Expose high potential spin bowlers to senior-elite performance environments, to: 1. Give spin bowlers an opportunity to 'settle' and demonstrate adaptability in unfamiliar and challenging elite environments. 2. Provide spin bowlers with an insight into the demands of elite cricket, consequently highlighting areas for further development. 3. Allow opportunities for cricket officials to challenge and confirm beliefs surrounding the potential of a spin bowler, both within and outside of competition.
What to look for? (*Talent Identification Tips*)		Spin bowlers who demonstrate superior adaptability; typically achieving a first significant performance in their senior club cricket and Second XI county teams within a year of debut.		Spin bowlers who become first-choice for their First XI County team within a few years of debut. Spin bowlers who adapt to new and unfamiliar surroundings quickly pre-First XI debut, and gradually becoming assured and comfortable, once in the First XI environment.
What to find out? (*Intelligence*)		When spin bowlers achieve their first significant performance for their senior club and Second XI county teams.		When spin bowlers achieve their first significant performance for their senior club and Second XI county teams. How quickly spin bowlers become the 'frontline spin bowler' at their First XI County.
Pathway Implications (*Pathway Strategy*)		Promote adaptability. Foster 'safe to fail' challenging practice environments.		Provide appropriate 'step-ups' in challenge by exposing high potential spin bowlers to elite cricket environments (training, competition environments).

FINDING <u>#5</u>:

International spin bowlers had greater match experience than the county spin bowlers, specifically they:

a) **Bowled a significantly greater proportion of match overs than the county spin bowlers, up to the age of their First XI County debut (around age 20)** (~ 28% vs. 20% of team overs).

b) **Experienced greater game time up to the age of their international debut *at* around age 24** (~ 11,000 vs. 8,000 hrs; approximately 400 full days of cricket difference, with the biggest difference occurring from when the spin bowlers arrive into First XI County Cricket).

Actions:	Pre-Pathway (8-12)	Early Pathway (U13-15)	Mid Pathway (U16-18)	Late Pathway (18-21)
What to do? (*Talent Development Coaching Tips*)		Provide spin bowlers with as many competition overs as possible, particularly up to their First XI debut. If spin bowlers cannot get regular match time in the team, then try and source additional playing opportunities elsewhere, alongside providing ongoing scenario and performance-specific practice volume.		
What to look for? (*Talent Identification Tips*)				
What to find out? (*Intelligence*)		The proportion of match overs that spin bowlers bowl in all environments. The type and number of matches that spin bowlers play within a typical week.		
Pathway Implications (*Pathway Strategy*)		Build and make use of external links to source alternative competition for non-regular spin bowlers. Instil scenario and performance-specific practice volume into the curriculum.		

Conclusion

To conclude, the key findings from the present study revealed a combined pattern of 12 features of development, which discriminate between sub-elite and elite spin bowlers with very good accuracy. The discriminating features materialise to produce a development profile encompassing four major areas of development (Early Development; Pathway Milestones; Domain-Specific Activity; Pathway Performance Indicators). Follow-up analysis/testing on unseen data led to perfect classification, providing evidence of the model's generalisability. The study also serves to highlight both the importance of concurrently examining the multifaceted and complex nature of expertise development, *and* offers sophisticated analysis methods to achieve this, producing a series of applied recommendations for the consideration of the ECB. We suggest that priorities in England and Wales Cricket now lie in profiling youth spin bowlers against the model, to identify potential areas for development. To that end, it is equally important that current development processes in academies that appear to hamper or discourage development areas across the 12 features highlighted are addressed. A prospective replication study of these modern-day spin bowlers will indicate any similarities or differences in the pathways over time, and will serve to increase the probability of producing an oversupply of future international spin bowlers. Extended research exploring the precursors of sporting expertise would benefit most from investigating the microstructure of practice, to obtain a greater understanding of what likely constitutes 'desirable' practice environments.

Chapter 4

Separating the great from the good: Optimising challenge the key in the development of England's greatest batsmen?[8]

[8] This chapter is submitted for publication as:
Jones, B.D., Hardy. L., Lawrence, G.P., Kuncheva, L.I., Brandon, R., Such, P., & Thorpe, G. It ain't what you do it's the way that you do it: Optimising challenge the key in the development of England's greatest batsmen? *Psychology of Sport and Exercise.*

Abstract

The present study examines the predictive power of the nature and microstructure of practice activities in a comparison of super-elite and elite cricket batsmen, domains of expertise development largely unexplored. Research exploring precursors of expertise typically examines a narrow pool of variables in isolation, such as practice quantity, using linear analysis techniques; the present study modelled the development experiences of super-elite and elite cricket batsmen by adopting non-linear machine learning (pattern recognition) techniques, to examine a multitude of variables across a number of theoretically driven expertise domains. Results revealed that a subset of 18 features, from 658 measured, discriminated between super-elite and elite batsmen with excellent classification accuracy (96%). The external validity of this new model is evidenced by its ability to also correctly classify data obtained from six unseen batsmen with 100% accuracy. Our findings demonstrate that super-elite batsmen undertook a larger volume of skills-based practice (hours) that was both more random, and more varied in nature, at age 16. They subsequently adapted to, and transitioned across, the different levels of senior competition quicker. The findings suggest that experiencing challenging skill-based, and psychological-based practice, relatively early in development, is a catalyst for progression to super-elite expertise. Application of this holistically-driven, non-linear methodological approach to other domains of expertise would likely prove productive.

KEYWORDS: expertise development; play; deliberate practice; microstructure of practice; skill acquisition; adaptability

Current knowledge from expertise research suggests that the attainment of expertise is highly likely the end-result of an enormously complex interaction between genetic and developmental factors (Johnston et al., 2018; Baker & Cobley, 2013; Baker et al., 2018). In a recent review, Rees et al. (2016) argue that differences in early experiences, preferences, opportunities, habits, training and practice activities are the strongest determinants of mastery in the expertise development process. Exploring the practice biographies and developmental histories of experts can therefore aid the identification of the determinants necessary for nurturing the development of expertise.

Volume of domain-specific practice is a widely reported precursor of expertise. For example, Ericsson et al. (1993) demonstrated that expert musicians had accumulated over 10,000 hours of 'deliberate practice' by age 20, whilst amateurs had only accumulated 2,000 hours, suggesting that deliberate practice is a precursor of mastery. The findings led to the development of the deliberate practice theory, which advocates a mechanism for developing expertise, centred on modifying the difficulty of practice commensurate with the skill level of the performer.

Age of specialisation is reported to influence volume of practice (Ericsson et al., 1993). Specifically, promoting 10,000 hours drives early specialisation, where sport involvement is focused on the performance demands of a single sport with little participation outside of this activity. Late specialisation, on the other hand, promotes early diversification and 'play'; activities which are fun, free from specific focus and provide immediate gratification, and places less emphasis on practice volume pre-specialisation (Cotè et al., 2007). However, emerging research suggests that the reported relationship between age of specialisation and practice volume is not necessarily always linear, since both elite athletes and cricketers are reported to have undertaken a larger volume of domain-specific practice, compared to the sub-elite, despite specialising later in development (Güllich, 2018; Chapter 3).

In addition to deliberate practice theory, there are a number of talent development models originating from the psychology, physiology, education or pedagogy disciplines: Developmental Model of Sports Participation (Côté et al., 2007); Long-Term Athlete Development (Balyi & Hamilton, 2004); Differentiated Model of Giftedness and Talent (Gagné, 2004); Athletic Talent Development Environment model (Henriksen et al., 2010). All of these models have both advanced our understanding of expertise development, and served to fill a gap between theory and applied practice. However, their generic nature presents challenges for identifying 'optimal' practice environments in sport. These challenges can be partly attributed to the additive effects observed within most talent development models that are suggested to develop expertise.

Environmental factors are reported to influence the development of expertise; a corpus of research has examined the prevalence of the RAE in performers with varying levels of expertise (for a review, *see* Baker et al., 2010). Whilst current knowledge suggests that RAE contributes to the efficient turnover of super-elite performers (e.g., Jones et al., 2018), its precise function within the development of expertise is less understood, highlighting the need for direct measurements of the hypothesized mediating factors of RAE. That said, examinations of RAE prevalence amongst holistic studies of expertise development, could highlight overlap between the explanations provided for RAEs observed in elite performers, and their discriminating developmental experiences, and advance understanding of the underlying mechanisms of RAE indirectly as a result.

Demographics are reported to impact on the development of expertise further. Examination of performers' birthplace revealed that small-to-medium communities provide favourable environments for developing elite athletes, suggesting that 'talent hotspots' may exist (MacDonald, Cheung, Côté, & Abernethy, 2009). However, the majority of birthplace research does not account for regional variations in general population distributions (Wattie et al., 2018). Whilst the subtleties of support provisions within a performer's development environment are not well understood, it is clear that prospective super-elite performers benefit from interactions with families, coaches and other support networks during their development (e.g., Hopwood et al., 2015). Specifically, having an older sibling is reported to enhance early opportunities for play and practice, and exposure to challenges, in developing rivalry and competitiveness (Hopwood et al., 2015; MacNamara et al., 2010).

Despite all of the above, examinations of the microstructure of sport practice are limited within the expertise development field (e.g., Deakin & Cobley, 2003; Ford, Yates & Williams, 2010; Hüttermann, Memmert & Baker, 2014). That is, the influence of the structure of skills-based practice, on the existing relationship between practice quantity and expertise attainment, is less well understood (e.g., Chapter 3). Instead, much of motor learning research pertaining to the microstructure of practice has emanated from controlled laboratory experiments, with unskilled participants, and over short learning periods. In this setting, the contextual interference effect on practice has been most widely researched (for a review, *see* Brady, 2008). The contextual interference effect stipulates that multiple skills (or skill variations) are more effectively learned when there is interference present during practice (for a review, *see* Monsell, 2003). At a basic level, the interference is created by manipulating the structure of practice trials such that skills are learned in either a blocked or random fashion.

Random scheduling involves the learner being required to switch between the skills "randomly" throughout practice, whereas blocked practice requires the learner to practice one skill for a block of repetitions, before switching to the other skill (Farrow & Buszard, 2017). The conclusion is that although random practice has detrimental effects on performance during acquisition in the short-term, it facilitates learning in the long-term. This is achieved either by encouraging the performer to undertake more elaborate and distinctive processing from one trial to the next (i.e., the elaboration hypothesis, Shea & Morgan, 1979) or through forgetting and subsequently reconstructing an action plan each time that a skill is performed (i.e., the action plan reconstruction hypothesis, Lee & Magill, 1985).

Experimental research has demonstrated that high contextual interference places exceedingly high demands on cognitive processing (Broadbent et al., 2017), which could potentially inhibit the benefits typically found to emerge from such practice in laboratory settings. Hence, task difficulty, or skill complexity, relative to the performer, appear central factors in moderating the contextual interference effect. This position is consistent with the various accounts of learning, whereby learning is more robust when the task difficulty presents an optimal challenge to the performer (e.g., Challenge Point Framework, Guadagnoli & Lee, 2004; Deliberate Practice, Ericsson et al., 1993). The benefits of contextual interference extend to skills which demand the same class of actions (e.g., executing different batting shots), through practicing different variations of the skills (e.g., manipulating the direction, loft, pace of a batting shot), known as variable practice (Schmidt & Bjork, 1992). Whilst knowledge pertaining to the nature and microstructure of practice largely stem from lab-based research with novices, we can reasonably theorise that the precursors identified facilitate both learning, and the development of expertise in sport. That said, while there is clearly a place for such lab research, the literature is at a point where there is a need to validate the findings in the field (Farrow & Buszard, 2017). Consequently, combining the scheduling of random and variable practice, and gradually increasing contextual interference, as a function of task difficulty and skill complexity, could aid the optimisation of challenge for cricket batsmen (Guadagnoli & Lee, 2004).

The superior learning associated with random and variable practice conditions likely reflect the benefits of representative learning/practice design, which replicate the inherent variability that exists within international playing conditions, and is likely a critical factor in helping to facilitate adaptable movement patterns in batsmen (e.g., Pinder at al., 2011). In this regard, random and variable practice is likely most beneficial in an open loop sport, such as cricket, where a batsman's output is in direct response to the (unpredictable) opposition bowlers' deliveries (Porter & Magill, 2010). This is especially relevant, given that a batsman's ability to adapt, producing multiple shot types in an unpredictable (random) fashion, and manipulate the direction, loft and pace of shots according to environmental constraints (variability) represents a key performance indicator in international cricket. This benefit is also reflected in recent research revealing that elite rugby league players had been exposed to significantly more match-scenario practice than sub-elite players (Rothwell et al., 2017). One can reasonably extend the specificity of practice principle to the multifaceted nature of sport performance, where practice conditions closely matching the movements of the target skill and the conditions of the target context result in optimal learning, by recognising technical and psychological specificity as separate constructs (Henry; 1968, Lawrence et al., 2014). This is pertinent considering that a problem associated with the traditional scheduling of practice, is the development of skills in a non-pressurised environment, as a pre-requisite for subsequent performance of skills in pressurised situations, whereas competition demands the production of skills under pressure (Lawrence et al., 2014).

In summary, the current literature provides limited understanding of the *interaction between* developmental characteristics *and* practice activity. Consequently, if future research is to achieve a better understanding of optimal development environments, sport-specific examinations of the nature and microstructure of practice activity, alongside developmental experiences, are warranted, in identifying: the skills that were practiced; how this practice was structured and delivered; how frequently this was practiced; and how this practice changed over the course of development.

Pattern recognition models the multiple and complex interactions between features (variables), whilst accounting for the multifaceted nature of expertise, reflecting a holistic approach to identifying precursors of expertise. This methodology was recently applied to identify predictive features that discriminate between samples of super-elite and elite Olympians (Güllich et al., 2019), and elite and sub-elite cricketer spin bowlers (Chapter 3). Research examining the development of cricket batsmen is limited, however, a recent unpublished study of international batting performances has revealed that batsmen's ability to adapt to higher levels of performance in the face of challenges is strongly related to super-elite performance, indicated by the length of time taken to achieve 'significant' performance-related milestones (Barney, 2015).

The present study represents a watershed, by being the first in the field to quantitively examine the microstructure of practice amongst a truly elite (super-elite) sample. Furthermore, the study comprehensively explores the multifaceted and complex nature of expertise, by examining the nature and microstructure of cricket batting practice against the developmental histories of super-elite batsmen, using advanced non-linear pattern recognition techniques. This approach overcomes the limitations of existing analyses, allowing for a more fine-grained approach, by addressing questions such as, "to what extent is the relationship between volume of practice and super-elite batting expertise contingent on organisation of practice?". The research findings will enable understanding of the interacting features common to super elite batsmen, leading to a greater overall understanding of relative importance of batsmen's development provisions and experiences, and will assist with identifying and benchmarking the precursors of super-elite expertise.

Method

Participants

The total sample comprised 20 past and present batsmen, 10 of whom were super-elite (M_{age} = 36; *SD* = 6.3) and 10 were elite (M_{age} = 34; *SD* = 3.6) (*see* Table 1). Super-elite batsmen were sampled on the basis of the following three criteria, and were applied in order of appearance: had played for the England national team post-2004; possessed a robust technique that enabled them to thrive against world class pace or spin bowling; continuously produced match-winning performances for England in test or limited overs formats "when it mattered"[9]. Elite batsmen were sampled on the basis that they had maintained prolonged careers at the highest standard of domestic cricket, by playing in a minimum of 100 innings of First-Class county Cricket ($M_{\text{innings}} = 279$; $SD = 110$), and represented the pool from which all super-elite batsmen had emerged. However, none of the elite batsmen had played for England in any senior competition; batsmen still playing were deemed unlikely, by the ECB's National Lead Batting Coach, to represent England in the future. Elite batsmen selected for the study were subsequently matched to the individual super-elite batsmen based on three characteristics: career era (*played First-Class county cricket post-2004*); batting position (*opening/top order/middle order*); and educational background (*public/state schooling*).

[9] The second and third levels of criteria were determined by the ECB's technical director of elite coaching.

Table 1. Super-elite and Elite Participants Criteria

	Super-Elite	**Elite**
Common Criteria	England-qualified elite and super-elite cricket batsmen Sampled from First-Class County Cricket Grouped into pairs and matched on: career era, batting position, and educational background	
Age	36 Years ± *6.3*	34 Years ± *3.6*
# of Competition Innings Played	First-Class County: 407 ± *158* England senior team: 247 ± *67*	First-Class County: *270 ± 110*
Unique Criteria	1) Represented England senior team post-2004 2) Possess(ed) a technique to thrive against world class pace/spin 3) Continuously produced match-winning performance for England “when it mattered”	1) Maintained prolonged careers in First-Class County Cricket *(Minimum 100 innings)* 2) Had never represented England at senior level/or were deemed unlikely to

A clear distinction exists in the performance levels reached by the elite and super-elite; the super-elite represent a subsample of just 2% of English batsmen who played First-Class county cricket within the same era (2004-2016). This clear distinction in participant's level of expertise allowed a robust examination of the precursors of super-elite expertise.

Measures

Attainment of Batting Expertise Interview Schedule. A structured interview schedule was developed, comprising four sections. Section 1 (*Demographic information*), 2 (*Developmental sporting activity*) and 3 (*Cricket developmental milestones and performance indicators*) of the interview schedule were informed by previous research exploring precursors of expertise (Chapter 3; Côté, Ericsson, & Law, 2005; Hardy et al., 2013). However, refinements were made, based on theoretical developments, and inclusion of terminology appropriate for batting. Section 4 was developed specifically for the present study by the researchers, to address the dearth of research exploring the influence of the nature, and microstructure of practice, on the development of sporting expertise. Section 4 addressed key developmental stages along the ECB talent pathway by focusing on practice activity at age 16, 18 and 22. The questions in section 4 centred on the specific time-point of the cricket calendar that participants had reported engaging in the largest volume of practice (summer or winter). It was hoped that this method, of focusing on the time-point that each participant recalled doing most practice in at each specified age ,would alleviate some of the well-documented limitations with regards to retrospective recall, specifically surrounding the accuracy of responses provided (e.g., Hopwood, 2013), by. The developed interview schedule was then subjected to a 3-staged piloting process. Firstly, the ECB's Head of Science, Medicine and Innovation reviewed the interview schedule, and provided detailed constructive feedback for refinement. Secondly, the schedule was piloted on a number of elite batsmen and England Development Programme batting coaches to assess the relevance of theoretical content and terminology against the structure of the talent pathway. A final pilot interview was then performed with the Director of England Cricket, who subsequently approved the study. The final interview schedule, comprising four expertise domains, along with an overview of the features collected from the interviews, can be found in the Supplementary Information.

Methodological Design

'Super-elite' sportsmen are, by definition, extraordinary, and we adopted multi-level stringent criteria to represent their superior level of expertise; a sample classification method advocated by Jones et al. (2018). Consequently, the present study addressed inconsistencies observed in the sampling classification methods of previous research, owing to the simplistic dichotomisation of levels of expertise (Coutinho et al., 2016). The batsmen's existing level of expertise demonstrate that, overall, the effects of their developmental experiences and practice histories are durable, meaning that identifying the enduring discriminating factors will address the drawbacks of short transfer effects in previous research. The Super-elite sample was identified first, and the elite participants were subsequently matched (*career era, batting position,* and *educational background*) according to a matched-pair design; a similar design to that used in the Hardy et al's (2013) seminal study. The matching of participants on the key characteristics identified assisted in exploring why batsmen digress in their eventual expertise, despite their common characteristics, enabling the present study to address the 'what makes the difference?' question comprehensively. The quantitative dataset comprised 20 participants (objects), with 658 features (variables), and this self-reported data were directly inputted into Microsoft Excel during the interviews, and collated prior to analysis.

Procedure

Following institutional ethical approval for research involving human participants, the participants were recruited by the Director of England Cricket, and the National Lead Batting Coach. All participants provided written informed consent in advance of interview. Each structured interview lasted approximately 3 hours, was recorded using a digital Dictaphone, and was designed such that all data were quantitative. Once all interviews had been completed, data were standardized, and then analysed using pattern recognition approaches, with the primary aim of determining the features from the practice biographies and developmental histories of batsmen, that best discriminate between the super-elite and elite.

Analytical Strategy: Overview

Pattern recognition analysis has been developed in bioinformatics to solve the problem of classifying objects on the basis of their features (Hastie, Tibshirani, & Friedman, 2003), and has recently been applied within sport sciences. The analysis offers a non-linear approach to analyse data multidimensionally, representing the multifaceted and complex nature of expertise (Chapter 3; Güllich et al., 2019). Pattern recognition analysis overcomes the limitations of linear techniques, which typically analyse features in isolation. This method employs modern computational power to iteratively analyse a large number of features to identify the pattern of features that best discriminate between different classes of objects (participants). Pattern recognition comprises 3 stages: feature selection; classification; and recursive feature elimination (for a detailed description of these procedures, *see* Appendix 1; Chapter 3; Güllich et al., 2019).

Feature selection identifies the individual predictive features that best discriminate between (the super-elite and elite) classes. Pattern recognition analysis requires a robust method of feature selection for such a "wide" dataset, where there are far more features than objects, preventing spurious results. The four feature selection methods utilised in the present study have been chosen because of their suitability for use with wide datasets: Support Vector Machine (SVM, Burges, 1998); Relief-F (Kira & Rendall, 1992b); Fast Correlation Based Filter (FCBF, Yu & Liu, 2003); and Correlation Attribute Evaluation (Hall, 1999). These four feature selection methods use very different criteria, consequently, the more times that a common feature is selected by different feature selection methods, the greater confidence can be placed in that feature's predictive power.

Classification involves the analysis of a specified subset of features, with the aim of discriminating between groups of classes. In the present study, feature subsets are derived from the feature selection protocol, and the pre-defined classes are the super-elite and elite, thus classification accuracy is determined by the number of batsmen that are correctly assigned as super-elite or elite. Once again, greater confidence can be placed in feature sets that have consistent rates of classification accuracy. Consequently, four different classifiers were applied to the feature subsets selected in the present study: SVM (as used in the feature selection, Burges, 1998); Multilayer Perceptron (MLP, Bishop, 1995); Naïve Bayes (NB, Hand and Yu, 2001); and Nearest Neighbour (Lazy learner, IB1, Duda et al., 2001).

Recursive Feature Elimination (RFE) (Guyon et al., 2002), also known as *'fitting'*, is a procedure that identifies the subset of features that predicts the class labels with highest classification accuracy, allowing us to provide the user with the optimal solution for a given dataset (Chapter 3; Güllich et al., 2019). RFE is applied to subsets usually consisting of a large number of features, where fewer, as opposed to greater, features are likely to offer the optimal solution.

Analytical Strategy: Summary

In the present study, the predictive power of the 658 features collected was assessed by ascertaining how accurately they discriminated between super-elite and elite batsmen. In order to extract discriminatory features from the data, we used the Waikato Environment for Knowledge Analysis (Weka, Hall et al., 2009). Weka is a machine learning workbench that offers a wide range of algorithms for data pre-processing, feature selection and classification (Witten et al., 2011). Both feature selection and classification methods were subjected to leave-one-out cross-validation, to mitigate the risk of overfitting, and to provide a more realistic prediction of the classification function on unseen data (generalisation performance) (Kuncheva & Rodríguez, 2018). The analytical strategy adopted in the present study is based on the strategy of Güllich et al. (2019).

Section Analysis. The first stage of the analysis involved applying the *feature selection* protocol to identify the predictive power of features from each of the four expertise domains of the interview schedule separately (demographic information, developmental sporting activities, developmental milestones and performance indicators, and the nature and microstructure of practice). Features from each section possessing the greatest predictive power were subsequently pooled together; the predictive power of features was determined by the consistency with which they appeared in the top-20 features selected by each of the outlined four feature selection methods. Using this procedure, three subsets of predictive features were selected, according to three different degrees of stringency (A, B, C) (*see* Figure 1):

Feature Subset (A): Features ranked in the top 20 discriminatory features by at least two out of four feature selection methods *(least rigorous/most liberal).*

Features Subset (B): Features ranked in the top 20 discriminatory features by at least three out of four feature selection methods.

Features Subset (C): Features ranked in the top 20 discriminatory features by all four feature selection methods *(most rigorous/most conservative).*

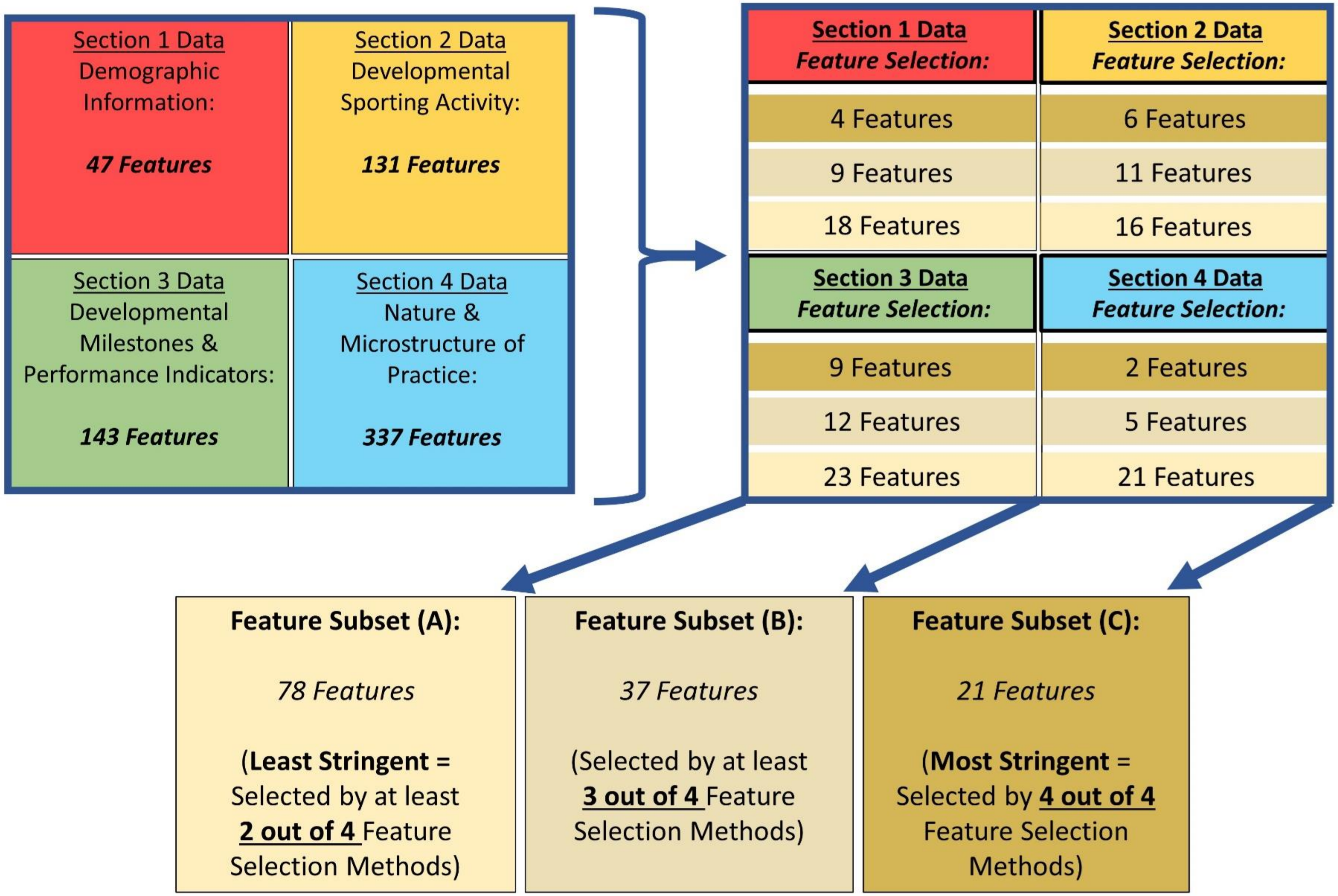


Figure 1. Feature selection summary for the section analysis: The consistency by which features appeared within the top-20 features for each of the four feature selection methods, creating three subsets of features with different degrees of stringency.

Subset Analysis

The subsets from each of the four expertise domains were then combined to perform a set of three omnibus analyses with varying degrees of stringency (A, B, C); these subsets cumulatively totalled 78 features. In light of the substantial number of (78) features that existed across the subsets, the first step of the omnibus analysis involved repeating the feature selection procedure within each feature subset (A, B, C), to assess the *relative* predictive power of their amalgamated features. Following this, classification protocols were applied, using the four classifiers outlined, to assess the combined discriminative power of the three feature subsets produced. For each of these subsets, the feature subset producing the highest overall classification accuracy was selected, and is presented in Table 2. Recursive Feature Elimination method (RFE) was subsequently applied to the three feature subsets selected, to arrive at an 'optimal' solution in the case of each subset, by only retaining the fewest number of features that discriminate between classes with the greatest accuracy. Finally, the three reduced (optimal) solutions were amalgamated into a single, final classification analysis, and are reported in the results section.

Table 2. Summary of the best solutions produced from the omnibus analyses.

	Omnibus A	Omnibus B	Omnibus C
Inputted Features	78	37	21
No. of Features Selected in Best Solution	19	9	17
Initial Classification Accuracy (Average)	92.5%	98.75%	91.25%
No. of Features Omitted	5	0	7
Final Solution: No. of Features	14	9	10
Final Solution: Classification Accuracy (Average)	98.75%	98.75%	98.75%
Final Solution: Feature Descriptors	- Volume of Cricket 'Play' Age 16 - Volume of Cricket Practice Activity within Busiest Practice Period Age 16 - Volume of Random-Varied Batting Practice with Maximum Variation (3 Variations) - Age Selected for Highest Level of Cricket Competition by Age 18 - Age Selected for Highest Level of County Cricket by Age 22 - Age Made Senior List A (Professional) Debut - Age Became the Best Batsman in their Second XI County Cricket Team - Development Time Missed Through Injury Between Ages 19-22 (Months) - Volume of Cricket Competition Age 21 - Volume of Total Cricket Activity Age 21 (Practice + Competition) - Volume of Cricket Competition Age 22 - Age Became One of the Best Batsmen in their First XI County Team - Became the Best Batsman in their First XI County Team (Outright) - Age Became the Best Batsman in their First XI County Team	- Volume of Random-Varied Batting Practice with Maximum Variation (3 Variations) - Age Selected for Highest Level of Cricket Competition by Age 18 - Age Made Senior List A (Professional) Debut - Age Became the Best Batsman in their Second XI County Team - Volume of Cricket Competition Age 21 - Volume of Total Cricket Activity Age 21 (Practice + Competition) - Volume of Cricket Competition Age 22 - Became the Best Batsman in their First XI County Team (Outright) - Age Became the Best Batsman in their First XI County Team	- Number of Older Siblings - Volume of Cricket Practice Activity Age 16 - Number of Shots Practiced Randomly Age 16 - Volume of Random-Varied Batting Practice with Maximum Variation (3 Variations) - Years to Transition from Club Cricket Aged 16 to First XI County Cricket Team - Age Selected for Highest Level of Cricket Competition by Age 18 - Age Became the Best Batsman in their Second XI County Team - Volume of Cricket Competition Age 21 - Volume of Total Cricket Activity Age 21 (Practice + Competition) - Age Became the Best Batsman in their First XI County Team

Results

Final Classification Model: Overview

The omnibus analyses produced three different solutions (A, B, C), each discriminating between super-elite and elite batsmen with excellent accuracy. Each solution reflects the result of slightly different feature selection, classification, and recursive feature elimination, conducted during the omnibus analyses (*see* Table 2). These three solutions collectively contain a total 18 different features (which do not all appear in any one solution), and for sake of inclusiveness, the 18 features were inputted into a combined final classification model, also producing excellent accuracy (*M* = 96.25%):

- Support Vector Machine (SVM) Classifier: 100%
- Multilayer Perceptron (MLP) Classifier: 100%
- Naïve Bayes Classifier: 90%
- Nearest Neighbour (Lazy learner, IB1) Classifier: 95%

This multidimensional approach dictates that the 18 features discriminate as a combination *exclusively*, and as such, these findings should be interpreted and applied as a holistic profile across academic and applied sporting domains. Nevertheless, the descriptive statistics and direction of the 18 discriminating features are presented individually in Table 3 for information.

Table 3. Unstandardised descriptive statistics of the 18 development features that discriminate between super-elite and elite batsmen.

#	Feature	Direction (+ / -)	Super-elite			Elite		
			Mean	Median	SD	Mean	Median	SD
1	Number of Older Siblings	+	1.20	1.00	1.07	.40	0	.91
2	Volume of Cricket Practice Activity Age 16	+	355.00	401.70	167.00	198.00	201.50	36
3	Number of Shots Practiced Randomly Age 16	+	10.20	11.00	2.00	8.00	9.00	1.94
4	Volume of Cricket 'Play' Age 16	+	129.72	102.29	86.09	42.69	22.37	38.30
5	Volume of Cricket Practice Activity within Busiest Practice Period Age 16	+	243.00	260.00	112.00	154.00	138.00	31.00
6	Volume of Random-Varied Batting Practice with Maximum Variation (3 Variations)	+	103.35	78.32	79.47	19.50	0	34.88
7	Years to Transition from Club Cricket Aged 16 to First XI County Cricket Team	-	3.40	3.00	1.01	5.40	5.50	2.29
8	Age Selected for Highest Level of Cricket Competition by Age 18	+	17.50	18.00	.67	16.60	16.00	.80
9	Age Selected for Highest Level of County Cricket by Age 22	-	17.90	18.00	1.04	19.90	22.50	1.92
10	Age Made Senior List A (Professional) Debut	-	18.48	18.79	1.04	21.17	21.41	1.94
11	Age Became the Best Batsman in their Second XI County Team	-	19.50	18.50	2.59	23.30	23.00	2.38
12	Development Time Missed Through Injury Between Ages 19-22 (Months)	-	0	0	.20	1.32	.13	1.97
13	Volume of Cricket Competition Age 21	+	867.00	860.00	120.00	528.00	563.01	231.00
14	Volume of Total Cricket Activity Age 21 (Practice + Competition)	+	1206.00	1176.50	158.00	741.00	859.72	299.00
15	Volume of Cricket Competition Age 22	+	865.00	913.99	282.00	526.00	562.75	221.00
16	Age Became One of the Best Batsmen in their First XI County Team	-	20.60	20.75	2.24	25.00	26.00	2.87
17	Became the Best Batsman in their First XI County Team (Outright)	+	1.00	1.00	.16	.50	.50	.50
18	Age Became the Best Batsman in their First XI County Team	-	23.70	23.50	3.20	29.55	30.50	2.23

Final Classification Model: Summary

The results demonstrate that, compared to elite batsmen, super-elite batsmen: have *more* siblings who are older; engaged in a *larger* volume of cricket practice activity aged 16; undertook a *larger* volume of cricket practice within their busiest practice period aged 16; were engaged in a *larger* volume of cricket 'play' aged 16; practiced a *greater* number of shots during their random batting practice aged 16; undertook a *larger* volume of random-variable batting practice with maximum variation (3 variations) aged 16; took *fewer* years to transition between the highest level of club cricket played by age 16 to their First XI County Cricket debut; became the best batsman in their Second XI county cricket team at a *younger* age; made their List A (professional) cricket debut at a *younger* age; were *older* when selected for the highest relative level of general cricket competition by the age of 18[10]; missed *less* development time through injury between ages 19 and 22; were *younger* when selected for the highest level of county cricket competition by age 22; experienced a *larger* volume of cricket competition aged 21; accumulated a *larger* volume of total cricket activity aged 21; experienced a *larger* volume of cricket competition aged 22; became one of the best batsmen in their First XI County Cricket team at a *younger* age; were *more likely* to become the best batsman in their First XI County Cricket team; became the best batsman in their First XI County Cricket team at a *younger* age. The clear distinction in the 18-feature holistic development profiles of super-elite and elite batsmen are presented in Figure 2.

[10] This finding reflects that the super-elite were playing at a higher level of competition from a younger age.

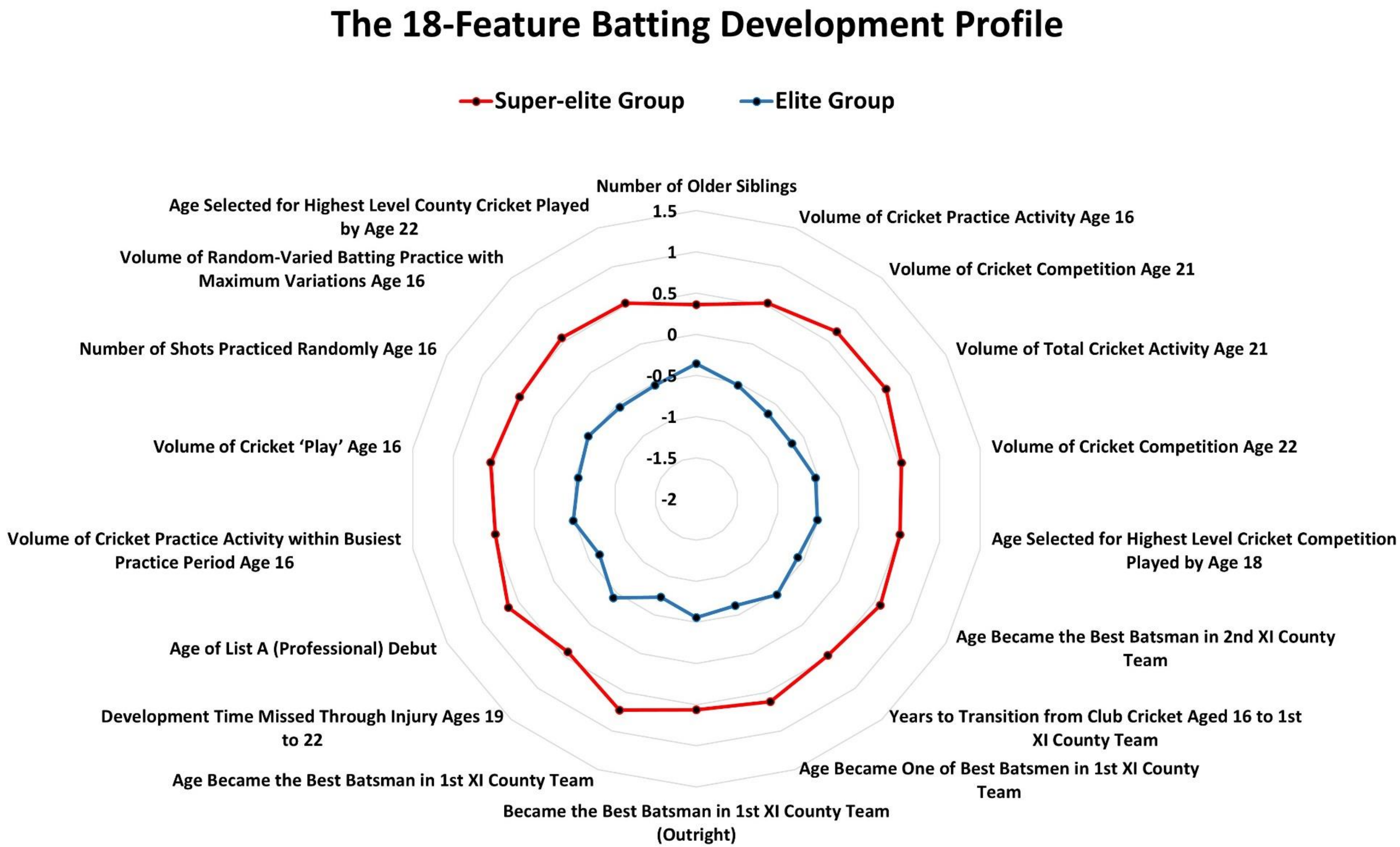


Figure 2. The discriminating development profiles of super-elite and elite batsmen. *Note.* Data points reflect the standardized mean values for each expertise class. A higher number is associated with the super-elite class. The values of negatively weighted features (outlined in Table 3) are reversed, in order to present the discrimination of the super-elite/elite development profiles through visual means.

The multistage approach of the analyses is underpinned by the premise that the more times a common feature appears across the different solutions, the more confidence that can be placed in the feature's importance. This consensus is displayed in Table 4. The Table highlights that 6 features, from a possible 18, were contained in all 3 solutions, demonstrating high consistency. A further 3 features were contained in 2 of the 3 solutions, demonstrating moderate consistency. The remaining 9 features were contained in 1 of the 3 solutions, demonstrating relatively low consistency (but high accuracy; *see* Discussion section for implications). An important disclaimer must be made here. The classification accuracies which we report for the above analyses may be slightly optimistically biased. The reason is because Weka's protocol for feature selection (LOO or not) is followed by another round of using the same data in order to train and test the classifier (LOO). In other words, the object set aside for testing has been "seen" during the previous training-and-testing protocol, when feature selection was carried out; this so-called "peeking" effect is indirect and ignored in many studies (Kuncheva, 2014; Smialowski et al., 2010). Nonetheless, one cannot make the claim that the classification accuracy on unseen data would exactly match the one achieved for this dataset, until the model has been directly tested (performed below).

Table 4. Level of confidence in feature importance; demonstrated by consensus of features contained within each solution (highest to lowest consistency).

Features Contained in Combined Final Classification Model	**Consensus Across Solutions**
Volume of Random-Varied Batting Practice with Maximum Variation Age 16 Age Selected for Highest Level of Cricket Competition by Age 18 Age Became the Best Batsman in their Second XI County Team Volume of Cricket Competition Age 21 Volume of Total Cricket Activity Age 21 (*Practice* + *Competition*) Age Became the Best Batsman in their First XI County Team	*Contained in 3/3 Solutions*
Age Made Senior List A (*Professional*) Debut Volume of Cricket Competition Age 22 Became the Best Batsman in their First XI County Team (Outright)	*Contained in 2/3 Solutions*
Number of Older Siblings Volume of Cricket Practice Activity Age 16 Number of Shots Practiced Randomly Age 16 Years to Transition From Club Cricket Age 16 to First XI County Cricket Team Volume of Cricket 'Play' Age 16 Volume of Cricket Practice Activity within Busiest Practice Period Age 16 Age Selected for Highest Level County Cricket by Age 22 Development Time Missed Through Injury Between Ages 19-22 Age Became One of the Best Batsmen in their First XI County Team	*Contained in 1/3 Solutions*

Confirmatory Model Testing

The 18-feature model discriminates between super-elite and elite batsmen with excellent accuracy; the next step was to test the model's ability to generalise (and thus predict) unseen datasets, i.e., batsmen who were not included in the original analysis. To do this, we utilised the interview data of 6 additional English batsmen, 3 of whom were classified as super-elite, and 3 of whom were elite. The existing 4 classifiers ever-present during the omnibus analyses were adopted for model, and the results are reported below:

- Support Vector Machine (SVM) Classifier: 100%
- Multilayer Perceptron (MLP) Classifier: 100%
- Naïve Bayes Classifier: 100%
- Nearest Neighbour (Lazy learner, IB1) Classifier: 100%

Model testing revealed 100% classification accuracy across the 4 classifiers, validating the 18-feature-model's generalisability on 6 unseen datasets.

Discussion

The present study developed and employed a novel method to examine the combined contribution of the nature and microstructure of practice, with developmental experiences, to understand '*what makes the difference*' in developing super-elite expertise. Results revealed a predictive model containing 18 features, from a possible 658, that discriminated between super-elite and elite batsmen with excellent accuracy (96.25%). Subsequent validation analysis of the final 18-feature model using an unseen dataset of six batsmen revealed a perfect (100%) classification fit of this testing data across four classifiers used, providing early evidence of the model's external validity. Furthermore, the multistage omnibus analyses contained degrees of stringency, enabling different confidence levels to be attached to different subsets of the 18 features. The study adds to the extant literature in a number of ways. First, it examined the microstructure of practice in a sample of truly elite sportsmen, rather than solely "counting hours”. Second, it utilised a serial framework that connected constructs, previously only examined disparately. Third, the non-linear capabilities of machine learning enabled exploration of the multiple and complex interactions between individual features, thereby contributing a holistic understanding of the multifaceted and complex nature of expertise. The discussion follows the temporal sequence of development; the 18-feature model is subdivided into 3 areas of development: Type and Volume of Activity; Transition; Adaptability.

Type and Volume of Development Activity

Super-elite batsmen undertook a larger volume of cricket practice aged 16, compared to the elite, both across the calendar year, and their most concentrated period of practice (summer *or* winter). This finding is consistent with the corpus of research attributing the development of expertise to vast quantities of domain-specific practice (e.g., Ericsson et al., 1993).

Examination of the microstructure of practice at age 16 revealed that super-elite batsmen had also undertaken a larger volume of random practice with greater variability, discriminating them from the elite. Specifically, super-elite batsmen deliberately applied more variations to their shots during random batting practice; these shot variations were direction, loft and pace in the present study. In addition, the super-elite’s random practice was more random in nature aged 16, as they practice a greater number of shots in a random order. These findings demonstrate that structuring practice to contain random practice *and* variability of practice relatively early in development (aged 16), represents a mechanism for increasing contextual interference, a precursor of super-elite expertise. This furthers our conceptual understanding, given that these concepts have typically been researched in *isolation*, and have not previously been concurrently measured in a super-elite sample in an applied setting (Farrow & Buszard, 2017). Although highly random and varied practice is considered detrimental to performance during early skill acquisition, due to the increased challenge associated with its dynamic nature (Lin, Fisher, Winstein, Wu, & Gordon, 2008), the present findings suggest that it offers long-term benefits. The most parsimonious explanation for the present findings, relate to the superior long-term learning retention associated with higher contextual interference and variable practice (for a review, *see* Monsell, 2003). Moreover, these findings offer a serial framework by which 'domain-specific' practice hours, may be constructed within an elite sporting environment, by addressing the question of '*what, how and when?*' should one practice, rather than the historically answered question of '*how much?*'.

The mechanism via which the super-elite may develop from performing (challenging) practice poorly during skill acquisition, to achieving mastery, is intriguing, as it highlights a disparity between the indicators of elite performance at senior and youth levels. Gradual improvement of performance is suggested to be contingent on three conditions: level of challenge; availability of feedback; and opportunity for error detection and correction (Ericsson et al., 1993; Guadagnoli & Lee, 2004). Whilst 'optimal' challenge was not directly measured in the present study, the additional information presented by the higher volume of more random and varied practice undertaken by super-elite at batsmen aged 16 is indicative of greater nominal difficulty (challenge), when compared to practice conditions with lower contextual interference and variability (i.e., blocked and constant practice) (Shea & Morgan, 1979). Furthermore, ratings of mental effort and execution difficulty during practice did not discriminate between the super-elite/elite at age 16. This likely represents the functional task difficulty posed by the differing practice conditions relative to each group. Consequently, the present finding suggests that the super-elite's higher contextual interference and variability during their cricket batting practice at age 16 could have been a mechanism for optimising challenge during learning. However, this practice, whilst more challenging, also suggests dynamic, and therefore less repetitive practice; this is demonstrated by the super-elite's reporting that a greater volume of their cricket activity was representative of play than the elite, at age 16 (i.e., fun, free from specific focus and provide immediate gratification).

Super-elite batsmen have more older siblings than elite batsmen; this is consistent with past research at the *elite* level, where having an older sibling is a common circumstance in performers (Hopwood et al., 2015). We suggest that the present finding represents a pronounced sibling effect, resulting from heightened competitive exposure to multiple older siblings. These challenging sibling dynamics can foster resilience, and equip performers for coping with future high-level challenges (MacNamara et al., 2010). This finding could partly explain the super-elite's ability to cope, and thrive, under challenging circumstances during development, reflected in both their ability to persevere under more challenging practice conditions, and the superior adaptability demonstrated, upon transitioning to higher levels of competition.

The super-elite's larger competition volume at ages 21 and 22 discriminated them from the elite; this period represents the two years preceding their international debut ($M_{\text{age}} = 23$). The super-elite's greater cricket activity volume (practice + competition) aged 21 is a product of their larger competition volume at that age. These findings are consistent with research demonstrating that elite (international) cricket spin bowlers experienced a larger volume of cricket competition than the sub-elite, up to their international debut age (Chapter 3). We propose that the super-elite's prolonged senior competition experience is partly indicative of the long-term impact of highly dynamic and challenging representative practice, offered by higher contextual interference and variable practice, extending the specificity of practice principle, and promoting implicit learning (Henry, 1968; Lawrence et al., 2014; Masters et al., 2008; Pinder et al., 2011; Rendell et al., 2009).

Transition

Super-elite batsmen transitioned from their highest level of amateur club cricket played by age 16, to professional First XI County Cricket, faster than the elite; this reflects that they were younger when they made their First XI County Cricket debut, and therefore playing at a higher level of competition from a younger age. The quicker transition rate between competition levels, demonstrated by the super-elite, mirrors previous research demonstrating that high potential performers maximise their development from an earlier age, show earlier improvements, and could ‘make their move’ sooner as a result (McCardle et al., 2017). This quicker transition was likely influenced by a larger volume of more random and varied practice at age 16. Specifically, the skill retention benefits associated with high contextual interference may have led to an ability to execute multiple shots, and apply more variations, in response to competition demands. The super-elite’s larger volume of challenging practice at age 16, quicker transition to senior competition representation, and extended competition volume thereafter, all cumulatively indicate that they were better equipped to deal with the heightened demands of each stage of the pathway, reflects the optimisation of challenge (Ericsson et al., 1993; Guadagnoli & Lee, 2004).

Elite batsmen experienced longer periods of absence from practice and competition due to injury, than the super-elite, during the early stages of their senior professional county careers (age 19-22). The present finding suggests that elite’s higher injury prevalence during this period led to their unavailability for selection on more occasions, and as such, could have contributed to the lower competition volume experienced at ages 21 and 22. The finding represents a ‘red flag’ to science and medicine teams in cricket, given that the super-elite were typically selected for their international debut soon after this period (M_{age} = 23).

Adaptability

The super-elite’s superior adaptability was first observed in the second tier of domestic county cricket (Second XI cricket), who were younger than the elite when they became the best batsmen in their teams. The super-elite were also younger when they became one of the best batsmen in their First XI County team, were more likely to become the best batsman (outright), and were younger when they became the best batsman, compared to the elite. These findings offer partial support to two bodies of cricket research, demonstrating that elite cricketers achieve their first ‘significant’ performance sooner than sub-elite cricketers, which is strongly correlated with international achievements (*see* Barney, 2015; Chapter 3). Superior adaptability could be an accelerating factor in transitioning across competition levels, given that they appear as successive occurrences in the super-elite’s development timeline (*see* Supplementary Information). The emergence of longer-term measures of adaptability, and the absence of short-term youth performance, as precursors of super-elite expertise within the present findings, reinforces the *long-term* skill retention benefits of practice outcomes that contain higher contextual interference and variability relatively early in the talent pathway (age 16) (for a review, *see* Brady, 2008; Monsell, 2003).

Limitations

There are a number of limitations that the critical reader may identify in the present study. Firstly, as with all self-report retrospective research, there is a risk of error in recall attached to findings (Côté et al., 2005; Helsen et al., 1998; Hopwood, 2013; Ward et al., 2004). To try and mitigate this, a matched-pair design was employed in the present study (e.g., Hardy et al., 2013; Güllich et al., 2019), meaning that participants were of a comparable age, educational background, and cricket playing era (*see* Method). Furthermore, given that section 4 of the interview schedule contained questions pertaining to the microdetail of practice at ages 16, 18 and 22, we attempted to alleviate the potential for recall inaccuracies career, by allowing participants to focus on the specific time point that they had reported engaging in the largest volume of practice during these ages (i.e., summer/winter). Consequently, it was inferred that potential recall inaccuracies owing to age would be approximately equal for both groups. Lastly, whilst the interpretation of the 18 discriminating features supports existing theory, they are largely speculative because of the descriptive nature of the research design; we have not explicitly manipulated any variables, but rather used advanced machine learning analysis techniques to classify expertise based on the practice biographies and developmental histories.

Implications for Research and Application

The present study is the first known to have applied a framework to measure the contextual interference and variability of practice effects in a truly elite sample. The super-elite's discriminating contextual interference and variable practice observed at age 16 occurred seven years prior to their international debut, aged 23. This suggests that research wishing to explore the effects of the microstructure of practice, in ecologically valid sporting situations, may require more long-term acquisition/practice periods than the short-term effects typically measured in laboratory research. Further examination of factors which moderate the contextual interference effect in sportsmen could lead to a better understanding of the relative contribution of the microstructure of practice in the development of expertise, representing a fruitful avenue of investigation for experimental research. Above all, the present findings demonstrate that the development of expertise is multifaceted and complex. It is therefore imperative that future expertise research extends this holistic approach to identifying precursors of expertise, through collecting 'wide' datasets across multiple expertise domains, including psychological and physiological domains (Güllich et al., 2019; Mann, Dehghansai, & Baker, 2017).

In addition to the study's discriminating features, there are 640 features, from the 658 theoretically driven features collected, which do not discriminate between the highest levels of expertise, and can, at the most basic level, be regarded as commonalities (for an overview of all features collected, *see* Supplementary Information). Several of these commonalities likely contain fundamental developmental experiences that would discriminate between elite and sub-elite batsmen, e.g., undertaking a sufficient volume of practice (Chapter 3).

The varying degrees of stringency applied to the analyses has implications for the application of the findings to the field. Specifically, 6 features (from the possible 18 that discriminated) were contained in all 3 solutions derived from the omnibus analyses, demonstrating highest consistency. A further 3 features were contained in 2 of the 3 solutions, demonstrating moderate consistency. The remaining 9 features were contained in 1 of the 3 solutions, demonstrating lowest consistency (*see* Table 4). Consequently, the authors recommend that the cricket national governing body in England should *act on* features contained in all 3 solutions, should *probably act* on features contained in 2 of the solutions, and *give consideration* to features confined to 1 solution. To better understand the complexities of the feature profiles of both super-elite and elite spin batsmen, a research working group was formulated, and was overseen by the corresponding author, consisting of three senior ECB officials whose roles were directly responsible with the talent pathway: Head of Science, Medicine and Innovation; Player Identification Lead; National Lead Batting Coach. Expert opinion was sought from these officials at various stages, leading to the production of a series of implications and recommendations for talent identification and development, based on the findings, which are presented to the reader below.

Implementation

What are the Differentiating Factors?

The ECB has conducted in-depth academic research with Bangor University, with the primary aim of determining the developmental features which differentiate (super-elite) International from (elite) County batsmen.

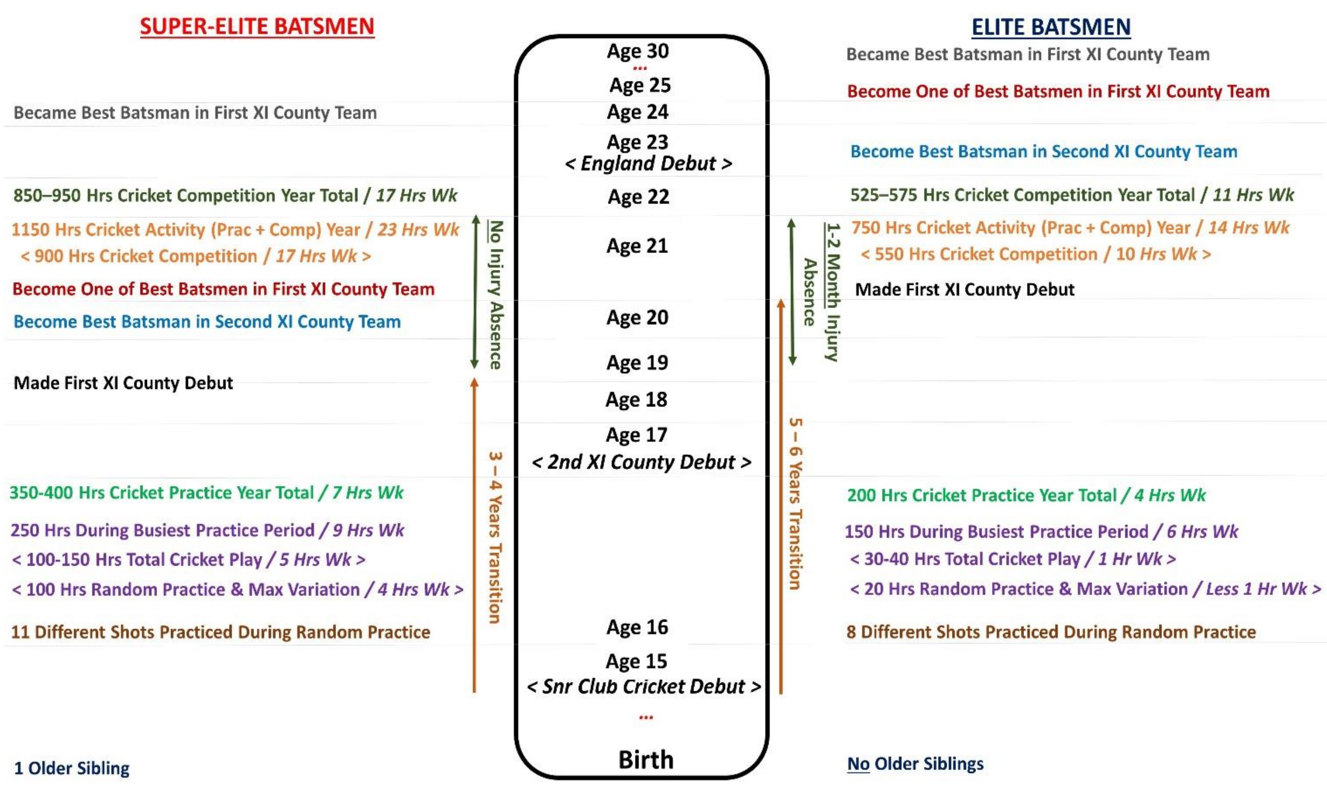
The key findings are that International players can be distinguished from County players of matched age and backgrounds by –

1. The volume and type of practice conducted during the pathway.
2. The speed of transition through the pathway and adaptation to Professional cricket.
3. The volume of match opportunity during their early career.

The International group comprised ten England players who have played in Test matches for England since 2004. They have all performed > 200 innings for England and senior ECB officials decided they had demonstrated quality performances versus International level pace and spin bowling. In contrast, the County group comprised ten 'twin' players, each with > 100 First-Class innings. They were matched with an England player on playing era and educational background. None of these County players have played (or deemed likely to play) for England.

Data was collected on every aspect of development history, from family background, school, sports participation, cricket development and details of the quantity and nature of cricket practice. Advanced analytics revealed 18 key features that differentiate England from County players, with excellent (96.3%) predictive accuracy. These differentiating key features are cited in the explanations below.

The Timeline below depicts the 18 differentiating features between the super-elite and elite.



Challenge and Specificity Findings

The evidence supports that International players conducted more challenging and specific practice and play than the County players.

Direct evidence is –

1) Greater volume of more 'Random AND Varied' practice at age 16 years (4 vs. 1 hour).
2) Greater variety of shots in practice at age 16.
3) Greater 'play' time at age 16.

Further direct evidence is that Internationals had +1 older siblings, therefore could have had more informal (competitive) play opportunities during childhood.

The ECB National Lead Batting Coach believes that high levels of match play and variety during practice is essential during the pathway ages (13-17 years).

Time on Task and Opportunity Findings

The evidence shows that International players spent greater time on task than County players.

Direct evidence is –

1) 7 vs. 4 hours per week practice average across the year at age 16.
2) 9 vs. 6 hours per week practice average at the peak time of year at age 16.
3) 2-3 match days per week vs. 1-2 match days average across the year at ages 21 & 22.
    - This is the equivalent of 120 vs. 80 days across the year.
    - This difference is not explained by greater winter opportunity for the Internationals.
4) Between the ages of 19-22 Internationals typically missed no time to injury vs. 2 months for County players.

ECB National Lead Batting Coach believes 'purposeful' practice in the nets to be essential and that Professional players need to display 'self-directed' learning by their early careers.

Transition & Adaptation Findings

The evidence shows International players transition and adapt faster than the County players.

Direct evidence is –

1) TRANSITION – Both groups debut at Senior Club level at 15 years, but Internationals take 3-4 years to transition to 1st XI First-Class or List A debut, versus 5-6 years for the County group.
2) TRANSITION – Specifically, Internationals continue to transition up levels of Cricket at 16, 17 and 18 years.
3) ADAPTATION – Internationals became 'one of the best' or 'the best batter' in their 2nd XI and 1st XI levels faster than the County players. E.g., 'one of the best batters' in 1st XI by 20-21 years compared to 24–25 years for County players.

What Does Random & Varied Practice Mean for Coaches?

The ECB National Lead Batting Coach defines three levels of batting practice below, that Coaches can deploy with young players. The first type is 'blocked and constant' and the second and third types are increasingly 'random and varied'.

1) **SINGLE SHOT PRACTICE**
   - AKA 'Repetitive Grooving' or 'Drilling'.
   - The objective of this is to get technically good at executing a specific shot.
   - E.g., Pull Shots or Front Foot Drives for 20-30 minutes.
   - Normally involves bowling machine or consistent feeds to similar line & length.

2) **MIXED SHOT PRACTICE**
   - AKA 'Random' or 'Mixing it Up'.
   - The objective of this is to develop the decision-making ability to pick line & length AND execute a technically sound shot.
   - E.g., Mixing between Front foot and back foot shots to the off-side.
   - This would require either side arm or real bowling deliveries of various line & lengths.

3) **SCORING SHOT PRACTICE**
   - AKA 'Net Challenges', or 'Nets with targets' or 'Constraints-based practice'.
   - The objective of this is to challenge the player to execute run scoring shots from varied line & length deliveries.
   - E.g., Take singles and hit boundaries, over the top or on the ground, to specific areas.
   - This would require either side arm or real bowling deliveries of various line & lengths and 'field settings' or 'target scoring areas'.
   - This type of practice can also be set up as middle wicket practice.

The scoring shot practice is more 'representative' and match-specific, and therefore essential for performance, alongside sufficient technical development from the single and mixed shot practice.

The more varied the practice– in terms of scoring shot options – the greater the challenge and suggested long-term benefit.

Evidence-Based Recommendations

These recommendations have been prepared for dissemination across the national game, and are included in the ECB's Talent Development Framework.

1. **<u>Talent Identification – 'What to Look for'</u>**
   For ID and Selection of County Batters:
   - Batters making fast and continual transitions from 15 through 18 years would be a positive sign.
   - Ask about family and informal cricket play during childhood years. Having older siblings to play with and/or completing multiple hours a week of cricket play in any form could be an indicator of future potential.

2. **<u>Talent Development – 'What to Do'</u>**

(a) For Batter *Programme* Design:
   - Ensure the right volume of practice is available at Age-Group/Academy levels.
     - Guideline = 7 hours per week annual average.
   - Ensure there is sufficient match play opportunity at Age-Group/Academy levels
     - Guideline = 2 matches per week during the summer.
   - Ensure there is sufficient opportunity of match days per week at Academy and early Pro career.
     - Guideline = > 100 match days in a year.

(b) For Batter *Practice* Design:
   - Ensure a significant proportion of 'time on task' is fun and competitive. The more cricket 'play' the better, through a combination of matches, scenario practice, and 'net challenges'.
     - Guideline = > 50% of total cricket practice time is perceived by young players as 'play'.
   - Deploy a significant proportion of practice to 'Random AND Varied' methods.
     - Guideline = split practice time appropriately between the 3 practice levels defined above (Single, Mixed and Scoring Shot).
     - Guideline – ensure Mixed and Scoring shout practice is as varied as appropriate.
     - Guideline = keep the challenge level for the player in the '7-8 out of 10 sweet spot', by switching between the levels and/or altering the variability.

3. **<u>Pathway Implications – ECB Strategy</u>**
   For England ID and Selection of Batters:
   - U19yr 1st XI debut coupled with becoming a 1st XI high performer by 20-21years is a positive indicator.
   - Multiple months missed through injury between ages 19-22 could be a red flag for a batter.
   - Development of an 'England Batter Developmental Inventory' may be useful to check high potential players 'timelines' and 'milestones.

Conclusion

In conclusion, a combined pattern of 18 developmental features, from a possible 658, discriminate between super-elite and elite batsmen with excellent accuracy (96%); follow-up testing provided evidence of the model's external validity. The overriding influence of challenge represents a foundational difference in the development of super-elite batsmen, compared to the elite, in what appears to be a race to the top. The super-elite's higher contextual interference, indicated by their larger volume of random practice, with greater variability, suggests that they persisted in this face of these challenges, despite the associated early performance detriments. Their additional heightened exposure to sibling rivalry, and associated setbacks, likely fostered resilience, and equipped them to cope with these high-level challenges from an earlier age. This is reflected in super-elite batsmen's ability to cope under more challenging circumstances in the short to medium-term, by adapting to these marked demands sooner than the elite, and subsequently transitioning across competition quicker. The superior long-term skill-retention of combining higher contextual interference with practice variability likely enables the super-elite to develop wider shot strategies, and adjust shot parameters, according to situational demands, more effectively in pressurised situations; this represents a performance demand of international cricket. All considered, the findings suggest that optimising challenge at both a psychological and technical level, is a catalyst for the development of super-elite expertise.

Chapter 5

PhD Impact

PhD Impact and Dissemination: Overview

Summary

The PhD programme delivered evidenced-based insights to address key performance questions developed in collaboration with ECB officials, and used a rigorous scientific approach, coupled with strong analyses capabilities, to make a lasting contribution to the ECB talent pathway's overall mission of "Ensuring the right quantity and quality of players are selected onto the pathway and into the England teams".

Outcomes of PhD and Applied Work [*Forecasted by 2020*]

1. ECB Research Provision

The Implementation of a 'tried and tested' method for utilising applied expert insight, leading to the development of a context-specific research framework, with direct application for practice:

- Formulation of an ECB research working group, led by the PhD candidate, comprising pathway Leads and Coaches (*see* 'Meetings' section & Appendix 2a).
- Research application was informed by a National dissemination phase; consisting of a series of consultation phases and knowledge sharing days, in collaboration with Directors of County Cricket and County Academies, and ECB pathway Coaches and Practitioners (*see* 'Meetings' and 'Presentations' sections & Appendix 2b).

2. ECB Talent Pathway Policy

The Identification of effective (evidence-based) skill acquisition methods and desirable development experiences, initiating a National review of cricket coaching curricula:

- Dissemination of discipline-specific 'best practice' guidelines for cricket development, produced in collaboration with pathway leads and coaches (*see* 'Presentations', and 'Meetings' sections & Chapters 3 and 4).

- Production of a Coach-education video resource centred on the PhD findings, disseminated Nationally via www.ecb.co.uk, and embedded into the curriculum of all ECB UKCC Coaching Awards (Levels 1 to 4) (*see* Appendix 2c).
- Directly informed the County Partnership Agreement (CPA) between the ECB and Counties, forming the 'Programme Standards' of definitive contact hours at Academy level and distinct specialist coaching support for both Academy and Elite Performance Programmes (EPP) (*see* Appendices 2d & 2e).
- The overarching findings have been converted into underpinning talent development principles, to form the 'What it Takes to Win' model, within the ECB's National 'Talent Development Framework', containing core principles for optimising development (*see* Appendix 2f).

3. ECB Talent Pathway Procedures

The Integration of the predictive models of elite performance, produced from the research, leading to the creation of pathway processes for optimising the identification, tracking, and development of cricketers across England and Wales:

- Profiling the development trajectories of youth cricketers against the benchmarked precursors of elite expertise, to track progress and identify areas for development (*see* Appendix 2g).
- Identification of individual and group-level Scout biases for CPD self-reflection (*see* Appendix 2h).
- Filtering and generating player lists for programme/team selection contention, e.g., at Young Lions long-list stage, ahead of shortlisting and selection meetings (*see* Appendix 2i).
- Introduction of 'National Talent Screening' to identify high potential cricketers (*see* Appendix 2i).

- Prediction of player 'England Readiness', based on the predictive findings identified; an objective information source used in all National selection meetings (*see* Appendix 2i).

4. Cross-Sport Application

- The impact of the research led to the PhD candidate's appointment as Affiliate Tutor for the English Football Association (the FA), delivering insights from the PhD research on the Level 2 award in 'Talent Identification in Football' to Heads of Recruitment, Managers, Coaches and Scouts at professional clubs in England (*see* Appendix 2j).
- The PhD candidate was consulted for the designing of the curriculum for the English Football Association's Level 3 award in 'Advanced Principles of Talent Identification and Development' (*see* 'Meetings' section & Appendix 2k).
- The PhD candidate was invited to take part in knowledge sharing sessions with the FA, Arsenal FC, and the West Indies Cricket Board (*see* 'Meetings' section).
- The nature and microstructure of practice research protocol has since been applied to UK Sport, Rugby Football Union, and Welsh Weightlifting PhD programmes (*see* Chapter 4 Supplementary Information for copy of protocol).

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Talent Manager and Regional Performance Managers During Monthly Meeting, Loughborough, UK. [Appendix 4].

Jones, B.D., Lawrence, G.P., Hardy, L. (2018). New evidence of the relative age effects in ‘super-elite’ sportsmen: A case for the survival and evolution of the fittest. *Journal of Sports Sciences, 36*, 697 – 703.

Jones, B.D., Hardy. L., Lawrence, G.P., Kuncheva, L.I., Du Preez, T., Brandon, R., Such, P., & Bobat, M. (Under Review). The identification of ‘game changers’ within England Cricket’s Developmental Pathway for Elite Spin Bowling: A Pattern Recognition Approach. *Journal of Expertise.*

Jones, B.D., Hardy. L., Lawrence, G.P., Kuncheva, L.I., Brandon, R., Thorpe, G. (Under Review). Separating the Great from the Good: Optimising Challenge Key in the Development of England’s Greatest Batsmen. *Psychology of Sport and Exercise.*

Sources to Corroborate the Impact

1. Dr Raphael Brandon, Head of Science, Medicine and Innovation, England and Wales Cricket Board.
2. David Parsons, Performance Director, England and Wales Cricket Board
3. Alun Powell, National Talent Manager, England and Wales Cricket Board (not involved in the project).
4. Mo Bobat, Player Identification Lead, England and Wales Cricket Board.
5. David Court, Formerly Regional Performance Manager, England and Wales Cricket Board, now Talent Identification Education Lead, English Football Association (not involved in the project).
6. Eddie Burke, Regional Performance Manager, England and Wales Cricket Board (not involved in the project).

Academic Publications, Conferences and Awards

BENJAMIN DAVID JONES (BSc Hons)

Publications in Refereed Journals

Jones, B.D., Lawrence, G.P., & Hardy. L. (2018). New evidence of relative age effects in 'super-elite' sportsmen: a case for the survival and evolution of the fittest. *Journal of Sports Sciences, 6*, 697-703. Doi: 10.1080/02640414.2017.1332420.

Jones, B.D, Woodman, J.P., Barlow, M., & Roberts, R. (2016). The darker side of personality: Narcissism predicts moral disengagement and antisocial behavior in sport. *The Sport Psychologist*, *31*, 109–116. Doi:10.1123/tsp.2016–0007 [BSc Research Project].

Chapters Submitted for Publication in Refereed Journals

Jones, B.D., Hardy. L., Lawrence, G.P., Kuncheva, L.I., Du Preez, T., Brandon, R., Such, P., & Bobat, M. (Under Review). The identification of 'game changers' within England cricket's developmental pathway for elite spin bowling: A pattern recognition approach. *Journal of Expertise*.

Jones, B.D., Hardy. L., Lawrence, G.P., Kuncheva, L.I., Brandon, R., & Thorpe, G. (Under Review). It ain't what you do it's the way that you do it: Optimising challenge key in the development of England's greatest batsmen? *Psychology of Sport and Exercise.*

Internal Publication [for Bangor University Staff and Students]

Jones, B.D., Hardy, L., & Kuncheva, L.I. (2017). Machine Learning Pattern Recognition Analysis: Procedures for SSHES. *Bangor University Internal Document*, 1-16 [Appendix 1].

Published Abstracts for Refereed Conference Presentations

Jones, B.D., Woodman, J.P., Barlow, M., & Roberts, R. (2014). Narcissism predicts moral disengagement and antisocial behaviour in sport. *Journal of Sports Sciences*, *32,* S16.

Jones, B.D., Lawrence, G.P., & Hardy, L. (2018). From Wall Street to expertise development: Predicting the rise and demise of talent investment by using machine learning to identify 'game changers'. *Journal of Sport and Physical Activity, 40,* S30.

Jones, B.D., Lawrence, G. P., & Hardy, L. (2018). Optimising challenge: Key to the development of 'super-elite' expertise. *Journal of Exercise, Movement, and Sport: SCAPPS refereed abstracts repository, 50*, S35.

Academic Conference Presentations and Symposia

Jones, B.D., Hardy. L., Lawrence, G.P. (2018). The Identification of 'Game Changers' in England Cricket's Developmental Pathway for Elite Spin Bowling: A Machine Learning Approach. *Oral Presentation at the annual 'Pan Wales Sport, Health and Exercise Sciences PhD Conference' in Bangor, UK, May 2018*.

Lawrence, G.P., Gottwald, V.M., & **Jones, B.D**. (2017). A Holistic Approach to Expertise Research Using Machine Learning. *Invited research symposium at the annual Expertise and Skill Acquisition Network (ESAN) in Coventry, UK, May 2017*.

Jones, B.D., Lawrence, G.P., & Hardy, L. (2017). Relative Age Effects in Super-elite Sportsmen: The Survival and Evolution of the Fittest? *Oral Presentation at the annual 'Pan Wales Sport, Health and Exercise Sciences PhD Conference' in Swansea, UK, May 2017.*

Jones, B.D, Woodman, J.P., Barlow, M., & Roberts, R. (2016). The darker side of personality: Narcissism predicts moral disengagement and antisocial behavior in sport. *Oral presentation at the annual 'European Network for Young Specialists in Sport Psychology' conference in Warsaw, Poland, May 2016.*

Jones, B.D., Lawrence, G.P., & Hardy, L. (2015). Evidence of the relative age effect at the 'super-elite' level in sport: A relatively long time coming. *Oral presentation at the annual 'Producing and Sharing Knowledge and Expertise in the World of Sport' PhD student conference in Copenhagen, Denmark, November 2015.*

Jones, B.D., Lawrence, G.P., & Hardy, L. (2015). Does the relative age effect exist at the 'super-elite' level in cricket? *Poster presentation at the annual Expertise and Skill Acquisition Network (ESAN) conference in Sheffield, UK, April 2015*.

Jones, B.D., Woodman, T., & Barlow, M. (2015). The darker side of personality: Narcissism predicts moral disengagement and antisocial behaviour in sport. *Invited oral presentation at the annual Association for Applied Sport Psychology (AASP) student conference in Loughborough, UK, February 2015.*

Jones, B.D., Woodman, T. & Barlow, M. (2014). The darker side of personality: Narcissism predicts moral disengagement and antisocial behaviour in sport. *Invited oral presentation at the annual British Association of Sport and Exercise Sciences (BASES) conference in Burton, UK, November 2014.*

Jones, B.D., & Woodman, T. (2014). The darker side of personality: Narcissism predicts moral disengagement and antisocial behaviour in sport. *Oral presentation at the annual British Association of Sport and Exercise Sciences (BASES) student conference in Portsmouth, UK, April 2014.*

Awards

Jones, B.D., Lawrence, G.P. **2019**

Impact Acceleration Grant: Economic & Social Research Council (ESRC) £10,000

Jones, B.D. **2018**

Impact and Dissemination Research Grant: England & Wales Cricket Board £6,000

Jones, B.D., Hardy, L., Lawrence, G.P., & Du Preez, T. **2017**

Grant to Extend PhD study (Chapter 3): England & Wales Cricket Board £5,149

Hardy, L., Lawrence, G.P., & **Jones, B.D.** **2014 – 2018**

Postgraduate Research Grant: England & Wales Cricket Board £15,000 p.a

Jones, B.D. (Supervised by Professor Tim Woodman) **2014**

'Best Undergraduate Presentation' at BASES National Student Conference

'Joint Best Research Project' within Bangor's School of Sport Sciences

Jones, B.D. **2011**

Bangor University Gwynedd Scholarship £1,500

Bangor Merit Scholarship £1,500

Industry Publications, Workshops, Presentations and Meetings

Authored Publications

Wigmore, T., **Jones, B.D**., Brandon, R., Thorpe, G. (2019, January 10). Solving England's Batting Crisis: Why Younger Brothers Could be the Key. *The Telegraph*. Retrieved from http://telegraph.co.UK/cricket/2019/01/18/solving-Englands-batting-crisis-younger-brothers-could-key/

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Presentations & Workshops

2015

- Presented my preliminary PhD research proposal to the ECB's Head of Science, Medicine and Innovation at the National Cricket Performance Centre (NCPC), Loughborough, UK, January 2015. Actions: proposal approved.
- Presented the historic graduation statistics of England Development Programme (EDP) 'talent testing' cohorts to the ECB's Head of Science, Medicine and Innovation and the England Development Programme (EDP) Head Coach in January 2015. Actions: decision immediately taken to extend talent testing for an additional year, to increase the longitudinal sample to 5 years of data.
- Presented my complete research proposal to The EDP's Operations Manager, Head Coach of the EDP, and National Performance Manager, in March 2015 at the NCPC. Actions: obtained 'buy-in' from the ECB pathway officials, and provisional piloting and study samples were drafted for Chapter 4.
- Presented my complete research proposal at the County Academy Directors conference at Trent bridge cricket ground, Nottingham, UK in October 2015. The audience included the ECB's regional Performance Managers and all County Academy Directors.
- Presented findings from an applied task at the 6-monthly scout CPD meeting, which included all pathway Scouts, regional Performance Managers and Chelsea FC's Head of Recruitment, at The NCPC in November 2015. The task was set by The EDP Operations Manager, to provide Scouts with feedback for their historic judgements regarding player potential. I provided group and individualised feedback on the specific scouting criteria that Scouts rate highly when judging a player as being 'high potential', compared to not.

2016

- I was invited to present my RAE findings (Chapter 2) to World Rugby's research consultant (Dr Ross Tucker) and research co-ordinator (Marc Douglas), delivered in February 2016 in Nottingham, UK. This significantly improved the quality of ideas presented in the manuscript shortly after, and generated several ideas for future RAE research for both parties.
- Presented an overview of my PhD research at the 'Innovation for Coaches Summit' at The NCPC in October 2016 to all of the ECB's National Lead Coaches and Directors of Performance. I then facilitated a discussion on how the research findings could be used to maximise talent development in cricket, which appeared to achieve 'buy in'.
- Presented my intended next steps with the longitudinal analysis project (forming part of my applied days) to the 'World's Best' project committee at the NCPC, in November 2016. The committee includes the ECB's Head of Science, Medicine and Innovation, the men's Senior Analyst (Nathan Leamon), and Pathway Performance Analyst (Kathryn Stuart). This was an important milestone, given how this work is now embedded into the world's best scheme of work, the findings of which will enable the ECB to benchmark developmental predictors of world class performance, and seek to gain a competitive advantage over opposition countries in doing so.

2017

- Presented at the ECB's 'Innovation for Coaches Summit' to all of the ECB's National Lead Coaches and Directors of Performance, in May 2017. This entailed a complete run-through of the spin bowling findings (Chapter 3), I also produced a handout for officials, and facilitated a discussion of the findings in groups, whereby a number of useful points were raised surrounding the application potential of the findings. This session served as a 'practice-run', prior to the dissemination of findings across the County pathway.

- Presented as part of a symposium at Blackburn Rovers FC in June 2017, with Blackburn Rovers' Head of psychological support (Dr Andy Hill). My presentation was themed 'Current Knowledge of Talent Identification and Development', and was based on the current literature, and knowledge from my PhD findings. The audience included Blackburn Rovers men's and women's pathway staff, as well as the wider grass-roots Coaching community in Blackburn. I also produced an infographic handout for Coaches to take away containing key recommendations (*see* Appendix 5 for handout).
- Co-presented the spin bowling development findings (Chapter 3) at the ECB's annual science and medicine conference in October 2017, at Tewkesbury park hotel, UK with the ECB's National Lead Spin Bowling Coach. The audience included all Directors of County Cricket, Coaches, and Practitioners from the professional County game. Following the presentation, we facilitated a discussion surrounding the extent to which the current cricket talent pathway in England maximises the spin bowling developmental factors, identified as discriminators and commonalities.
- Presented on the ECB's elite cricket Coaching master award (Level 4 UKCC) to spin bowling Coaches, at the NCPC, in October 2017. This presentation formed part of the professional development module, where candidates utilised the scientific evidence to develop insights for application to their Coaching roles. I facilitated a discussion to encourage the Coaches to use the evidence presented to optimise the development of spin bowlers within their immediate environments, to maximise the development of spin bowlers within their immediate environments, and consequently optimise the long-term development of spin bowlers across the English game.
- Presented current insights and applications of my PhD findings to the Player Insights Lead at The Football Association at a knowledge sharing session between the ECB and The Football Association at the NCPC, in October 2017.

2018

- Following phase #3 of the spin bowling development research working group, I co-presented the research to County Academy Directors, in March 2018 (https://www.ecb.co.uk/news/671734). Following the presentation, we facilitated group brainstorming tasks, to utilise the expertise of the Directors, asking them how they would recognise the precursors of expertise (i.e., the discriminators and commonalities) in the field, and importantly, how these attributes can be developed further within their pathways. The feedback obtained from this session was converted into practical strategies for implementing the recommendations (those previously outlined by the working group). It was expected that the collaborative nature of this session would facilitate the implementation of the recommendations, once disseminated.
- The ECB women's talent pathway recently underwent a restructure, and the pathway team were keen for the restructure to be underpinned by evidence-based insights. Consequently, I was invited to present a summary of my PhD findings to the ECB women's pathway team, which included the Head of Talent Pathway, High Performance Manager, and Pathway Coaches, at the NCPC in March 2018.
- Presented current knowledge from the longitudinal analyses of the ECB's talent identification sources, to a PhD student who is employed and sponsored by Warwickshire County cricket club, in May 2018. The talent testing protocol is being directly applied to Warwickshire County's age-groups, with the aim of identifying high potential players prospectively, also forming the basis of the student's PhD thesis. I have consulted with Warwickshire County cricket club during this process, and have since shared the talent testing protocol, to allow direct replication, and have provided guidance on project managing the testing event.

- Facilitated a knowledge sharing session for the age-group County Coaches present at Bunbury u15s regional tournament in Somerset, in July 2018. This session was integral to the consultation process highlighted in the spin bowling development research working group (phase #3). This knowledge sharing session targeted the recommendations previously thought to be most difficult to implement by the County Academy Directions, during the session in March 2018. The age group Coaches provided several strategies for implementing these recommendations into talent pathway processes. These strategies will be included as guidance, alongside the recommendations, once disseminated.
- Delivered a workshop within the 'Pathway Prediction' segment of the ECB's pathway CPD event in October 2018, at East Midlands Parkway, UK. The ECB officials present included the ECB's Performance Director, Technical Director of Coaching, Head of Science, Medicine and Innovation, National Lead Coaches, and Scouts. I presented the findings of the discipline-specific longitudinal analyses, containing the strongest predictors of pathway progression (success). Next, I split the room according to the discipline expertise of each official, i.e., batting, spin bowling, pace bowling, wicket-keeping. I asked each group to interpret their respective discipline-specific findings, and to outline the applied implications, based on their knowledge and experiences. Actions following the workshop included: plans to introduce a National screening process to identify 'raw attributes' in pathway cricketers; filtering decision making processes using the predictive factors, such as in generating scouting long-lists; and using the findings to aid predictions, such as England readiness assessments, based on the strongest predictors identified from the longitudinal analysis (*see* 'PhD Impact and Dissemination: Overview' section for more information & Appendix 3 for sample of content).
- Invited to present the conclusions of my PhD to the ECB's National Talent Pathway Manager, Regional Performance Managers, and Player Identification Lead at the monthly

pathway meeting, at the NCPC in November 2018. The team concluded that the findings should inform the principles of the ECB's imminent National 'Talent Development Framework' (*see* 'PhD Impact and Dissemination: Overview' section & Appendix 4 for sample of content).

- Presented current knowledge from the longitudinal analyses of the ECB's talent identification sources to the County Academy Director of Sussex in December 2018; this analysis was the basis of my applied work, and as such, is not detailed in the thesis. The Director is going to implement the aspects of the talent testing protocol that are shown to predict future success, as part of Sussex's development programme.

2019

- Invited to present to Arsenal FC's 'Performance and Research Team' at their training ground in London March 2019. This contact was initiated through a conversation between Arsenal's Senior Analyst (James Krause), and the ECB's Player Identification Lead. I presented on the research methodologies adopted within the PhD, and detailed how the findings had since been implemented into the ECB's pathway processes. The Arsenal officials subsequently presented the current research insight from their talent pathway.
- Presented a summary of my PhD findings to a Director of the West Indies Cricket Board, having originally been introduced by the ECB's Player Identification Lead in March 2019. I subsequently connected with the Director over Skype, where the Director highlighted several systematic issues within West Indies, including a lack of an evidence base for objective decision-making. The Director is currently in the process of arranging a meeting between the West Indies Directors and I, where I will present a research proposal, aiming to identify the discriminating developmental experiences of West Indies' super-elite cricketers, in addition to outlining strategies for mitigating bias in decision-making at board level.

- Invited to present at the ECB's County Academy Directors Conference on a consultancy basis at the NCPC, in March 2019. The workshop centred on the five key conclusions from my PhD. Following the presentation, I distributed a handout and facilitated a discussion surrounding how the findings could be used to aid the identification of players onto the talent pathway, and to optimise the development of players currently attached to the pathway (*see* Appendix 6). This workshop was followed by a presentation by the National Talent Pathway Manager who presented a prototype of the National 'Talent Development Framework', which is informed by the PhD findings.

- Consulted to co-present a workshop at the ECB's pathway CPD event in March 2019, at East Midlands Parkway, UK. The ECB officials present included the ECB's Performance Director, Technical Director of Coaching, Head of Science, Medicine and Innovation, National Lead Coaches, and Scouts.

Meetings

2014

- Attended a 'PhD handover' meeting, involving Dr Ed Barney (former Bangor/ECB PhD student), and all EDP Coaching and Administration staff, at the NCPC, in October 2014.
- attended the ECB's National 'Science and Medicine Conference' at St George's Park, in Burton-upon-Trent, UK, during October 2014.

2015

- Attended the EDP scouting meeting at the National Cricket Performance Centre, Loughborough, UK, January 2015, where I was introduced to the scouting procedures at the ECB. This meeting involved reviewing the policies of scouting, the annual timeline and the scouting forms. I identified areas for improving scouting procedures, and I was subsequently set tasks – to identify the best methods during selection meetings with regards to procedure – and to identify a measure of assessing scout decision-making accuracy.

- Co-ordinated a strategy meeting to prepare for the EDP's talent testing event at the NCPC, Loughborough, UK, February 2015. The meeting included the EDP's Operations Manager (Mo Bobat), and National Performance Manager (David Graveney OBE). Actions: I identified provisional key dates; talent testing roles; and an overall Gantt chart of Talent testing proceedings for the upcoming year.
- Met with the ECB's Head of Science, Medicine and Innovation at Bangor University, UK, in April 2015, to discuss the progress made during the studentship, and the research/applied work Gantt chart that I had previously produced. Actions: research and applied work commitments confirmed.
- Met with the ECB's National Lead Spin Bowling Coach (Peter Such), to discuss potential research opportunities, at Bangor university, in May 2015. Actions: developmental histories study commissioned (Chapter 3); draft sample identified; follow-up meetings arranged to develop appropriate methodology for interviewing.
- Chaired the EDP talent testing steering meeting involving the ECB regional Performance Managers, ECB Administrations, and National Performance Manager, at The NCPC in June 2015. Actions: finalised the timeline and responsibilities (previously provisional).
- Met with David Court (formerly ECB regional Performance Manager -now the Talent Identification Education Lead at the Football Association), at Bangor University in July 2015, to discuss future RAE research opportunities. Actions: Discussions contributed to the research design of Chapter 2, and a series of future research priorities.
- Attended the EDP u15-u18s shortlisting meeting and u19s (Young Lions) World Cup selection meeting at the NCPC, in June 2015. Actions: I made several recommendations to the EDP Operations Manager following this, including the need for submission of independent team selections, and displaying the top-5 highest ranked players by scouts for

each discipline to facilitate discussions during selection meetings. Both suggestions were implemented.

- Met with the ECB’s Head of Science, Medicine and Innovation at the ECB at the NCPC, in July 2015. Actions: received feedback on the first drafted iteration of the interview schedule, and I was also introduced to key ambassadors for the batting study (Chapter 4).
- Observed the Young Lions squad train at the NCPC during August 2015, to bring the theory currently embedded in Chapter 4’s interview schedule to life; this involved speaking to Coaches about different cricket examples that could be attached to the theory, to ensure that the questions and terminology were relatable to the players.
- Met with the ECB’s National Lead Spin Bowling Coach to review iteration 1 of the spin bowler developmental history questionnaire I devised, in August 2015. Actions: several changes were implemented following discussion.
- Met with the ECB’s Head of Science, Medicine and Innovation during August 2015 to put forward the updated qualitative and quantitative versions of the batting interview schedule (Chapter 4). Actions: the ECB Head of Science, Medicine and Innovation opted for the quantitative method, as this would provide the most comprehensive overview of the super-elite’s practice biographies and developmental histories, and possess less risk.
- Met with the EDP’s Operations Manager whilst watching the Super 4`s regional u17s tournament at the NCPC in August 2015, to discuss my observations from the previous shortlisting/selection meeting. Actions: Several tasks were assigned to me, to be carried out as part of my applied work.
- Attended the Young Lions Tri-series and World Cup squad selection meeting at the NCPC in September 2015. The selection procedures were visibly modified, based on my previous feedback to The EDP Operations Manager, and seemed to be more efficient. The EDP intake meeting followed this, and was based around the Scouts` recommendations made

earlier in the day. Actions: I made notes to feedback to the EDP Operations Manager, with notable strengths and areas for potential improvement.

- Led the EDP Talent testing at the NCPC in September 2015. As project manager of Talent testing, I co-ordinated the battery testing of approximately 80 youth cricketers, and over 25 staff, to ensure that the testing was conducted in alignment with the rigorous protocol set out, to safeguard the validity of the longitudinal research programme.
- Met with the ECB's National Lead Spin Bowling Coach at The NCPC in September, 2015, to discuss the latest interview iteration, based on previous feedback. Action: the spin bowling developmental history schedule was finalised (as shown in Chapter 3 'Supplementary Information' section).
- Attended the ECB's National 'Science and Medicine Conference' at Cranage hall, Crewe, UK, in October 2015.
- Met with the EDP Operations Manager at the NCPC in November 2015 to outline: (a) the implications of Ed Barney's PhD findings for current ECB applied practice, and (b) how my planned work in my project manager role for the longitudinal research programme (analysis of talent testing, scouting and performance statistics data) will impact on the ECB's talent pathway further. Actions: production of longitudinal analysis milestones, and I also agreed to contribute to the National talent pathway CPD day later in the year, to provide Scouts with feedback, specifically: *"which report criteria do Scouts appear to lean on, when making a decision regarding player potential?"*.
- Met with the EDP Operations Manager at the NCPC once again in November 2015, to provide definitive outcomes and timelines for my applied work for the ECB talent pathway, and to finalise my contributions to the scout CPD day.

2016

- Met with Iain Brunnschweiler, the EDP Batting Coach, in January 2016, to run a pilot of the 3-hour batting expertise development interview schedule for Chapter 4. Actions: he noted that the microstructure of practice section was “too loose” in its current form, and required breaking down to reflect the complex nature of batting practise. Thus, I made significant changes to the interview schedule based on this helpful feedback. Changes namely included aligning the batting shots with the deliveries batsmen faced, and separating blocked and random, and constant and variable practice domains individually. I re-piloted this updated interview schedule with the Coach in February 2016, and this was subsequently approved for further piloting.
- Met with the ECB’s Director of cricket (Andrew Strauss) at Lords cricket ground, London, UK, in March 2016 for the final stage of piloting the interview schedule for Chapter 4. Following the pilot interview, the Director approved the study, and agreed to become ambassador for participant recruitment.
- A PhD progress meeting took place between Bangor University and the ECB in July 2016, at Bangor University, where it was agreed that I would spend 2-days per week at the NCPC for the remainder of the PhD, to become fully integrated, and to facilitate participant recruitment and dissemination of findings.
- Constructed a visual presentation of the spin bowling findings (Chapter 3), and presented this to the ECB’s Head of Science, Medicine and Innovation in September 2016, who suggested minor changes. I subsequently presented this to the National Lead Spin Bowling Coach in October 2016. This presentation was a significant milestone, as I had not previously attempted to simplify largely complex findings, and improved my ability to explain and visualise complex data.

2017

- Met with the National Lead Spin Bowling Coach during January 2017, who was seeking clarity on the spin bowling development findings (Chapter 3), ahead of a presentation that he was delivering to Directors of cricket (senior level). Actions: The Coach was able to present the findings with confidence, whilst disclosing what they meant for spin bowling development, and perhaps of equal importance, what they don’t mean.
- Met with the ECB’s performance Director (David Parsons) and National Lead Spin Bowling Coach in February 2017, to formulate a strategy for presenting the spin bowling development findings (Chapter 3) to County Academy Directors in April. It was decided that the session will form a knowledge sharing day, seeking to utilise the expertise of Academy Directors, for production of future recommendations for applied practice, aligned with the findings.
- Invited member of two UK Coaching talent hubs (education and research) at Manchester Velodrome, in March 2017. I discussed my PhD research with senior academics from across sport science disciplines, and UK Coaching staff (including Head of Coaching; Vincent Webb). The hubs will take place every six months, with the overarching aim of bridging the gap between research and applied practice, leading to the commissioning of performance-driven research questions by UK Coaching.
- Met with the ECB Performance Director in April 2017 to consult on a dashboard measuring the effectiveness of the ECB’s talent pathway. This comprises of data from across the organisation, and tabulates this against the data publicly available for rival countries. Actions: I provided detailed feedback, increasing the rigour of the metrics used, to enable greater confidence in the conclusions being drawn.
- Met with the ECB’s National Talent Pathway Manager (Alun Powell) at The NCPC in June 2017, to discuss RAE research plans, and provide a summary of the findings (Chapter 2),

and how this outlook in England compares to rivals, along with their implications for the ECB's talent pathway. Actions: National Talent Manager to raise awareness of RAE across the talent pathway and to assist with any future research.

- **Development of the ECB research working group (July 2017 – present):** Following the conclusion of findings for Chapter 3, I devised a working group, consisting of ECB pathway officials, specifically: Performance Director; Head of Science, Medicine and Innovation; Talent Pathway Manager; Player Identification Lead; and National Lead Spin Bowling Coach. The intention of the working group was to bridge the identified gap between research conclusions, and their application to the ECB talent pathway, given how application of findings was typically halted once the 'lead person' left the organisation, historically. As this research design was purposefully developed with pathway officials, to be context specific, it was important that the beneficiaries (i.e., the pathway officials), benefitted from the pathway-specific research. The spin bowling development working group consisted of 4 phases. The batting research (Chapter 4) followed a similar process, encompassing a combination of phases 1, 2 and 4.
- **Spin bowling development research working group – phase #1**: The working group meeting took place following a Young Lions fixture in Chesterfield, during July 2017. Ahead of this meeting, I had analysed the 81 common features (non-discriminators) between the elite and sub-elite groups, to eliminate the statistically 'equally irrelevant' features in the development of spin bowling expertise. I then asked the working group members to preselect 10 features, from the remaining features, that they believe to be necessary for having a successful County (domestic) career. I presented an overview of the discriminating findings, and timeline of these. Next, a discussion surrounding the consistency of features preselected by officials took place, and resulted in the selection of 18 equally important features for progressing into senior County cricket.

- **Spin bowling development research working group – phase #2**:

  Following phase #1, I devised a storyboard comprising of the 12 discriminating factors, and the 18 equally important commonalities identified by the working group. The storyboard centred on a research-driven interpretation of the findings, coupled with the applied insight that I had developed during my PhD. I shared the storyboard (with a voiceover intact) to the working group officials, asking them to produce their personal implications from the storyboard, across highlighted areas of development, and met with the officials at the Super 4s tournament in August 2017 to record their implications.
- **Delivering the Football Association talent identification level 2 award: August 2017 – present:** I am employed as an affiliate tutor role for the Football Association, which involves presenting the key principles of talent identification to Heads of recruitment, manager, Coaches and Scouts to professional clubs across the English Football League structure. I have taken this opportunity to share insight from my PhD findings, specifically including writing effective match reports, mitigating bias in decision-making, non-linear talent development, and structuring practice sessions for effective learning (*see* 'PhD Impact and Dissemination: Overview' section for more information).
- **Spin bowling development research working group – phase #3**:

  Following the collation of the implications produced by the working group officials during phase #2, we met as a collective during October 2017, to scrutinise the implications, and convert them into recommendations. The National Lead Spin Bowling Coach then consulted two County Academy Directors, who acted as 'critical friends', in scrutinising the drafted recommendations, prior to wider consultation. The National Lead Spin Bowling Coach and I subsequently presented the recommendations to the County Academy Directors in March 2018, and again to Pathway Coaches during July 2018, to gather insight as to how the recommendations could be applied to the academy pathway (*see* ‘Presentations’ section).

- Contributed to a meeting between the ECB’s senior men’s analyst, and Professor Lew Hardy at Bangor University, in November 2017. The senior analyst had declared an interest in the machine learning techniques utilised in my PhD studies, and wanted to learn more, so as to apply these techniques to deliver frontline performance solutions from the projects that he is leading on.

2018

- **Consulting role for the Football Association talent identification level 3 award:** Invited to consult on the Football Association talent identification level 3 award at Stoke City FC, UK, in February 2018. The invitation was based on the research I had undertaken at the ECB. The level 3 award aims to advance candidates’ understanding of advances principles of talent identification. The candidates are officials from professional clubs (including Heads of recruitment, Managers, Coaches, Scouts, and Sport Sciences Practitioners). I made several recommendations aligned to the findings of my PhD, which were implemented into the curriculum, including the need for collection of historic RAE data, to assess prevalence in youth pathways, increasing knowledge of RAE function in long-term development. I also issued guidance on how psychological and social behaviours may be recognised in practice (*see* ‘PhD Impact and Dissemination: Overview’ section for more information).
- Attended the ECB talent pathway CPD event in April 2018 at East Midlands Parkway, UK, involving the ECB’s National Lead Coaches, Directors of Performance, Practitioners and Scouts.

- **Spin bowling development research working group – phase #4**:

  Feedback collected from the consultation period earlier in the year were discussed in this meeting, at the NCPC, in August 2018. Specifically, the feedback led to the inclusion of specific strategies, alongside the proposed recommendations, to provide officials with guidance for applying these recommendations, across the game (*see* Chapter 3 'Implementation' section). Following this, I presented a strategy for disseminating the recommendations. This was an educational video, featuring a storyboard of the findings, and Coach interviews, who advocated the recommendations. This strategy was approved, and will be commissioned in 2019 (*see* 'PhD Impact and Dissemination: Overview' section for more information).

- **Batting development findings working group – meeting #1**:

  Met with the ECB's Head of Science, Medicine and Innovation, and Talent Pathway Manager in September 2018. The meeting was called by the Talent Pathway Manager, who wanted to draw on evidence from the batting development findings (Chapter 4), to assign minimum practice time requirements to the County pathway. These requirements subsequently formed part of the County partnership agreement (CPA) between the ECB and representative Counties (*see* 'PhD Impact and Dissemination: Overview' section for more information).

- Met with the ECB's Player Identification Lead for a daylong meeting at The NCPC in September 2018, to discuss the (preliminary) findings from my longitudinal analyses of the ECB's talent identification sources. We spent the duration of the meeting interpreting the findings from over 20 different analyses outputs, and selected a proportion of the most conclusive findings, to form the 'Pathway Prediction' segment of the ECB pathway CPD event, taking place in October 2018 (*see* 'Presentations' section). The event will highlight the strongest predictors of pathway progression to the ECB officials, based on preliminary insights from the longitudinal findings.

2019

- **Batting development findings working group – meeting #2**:

  Met with the ECB’s Head of Science, Medicine and Innovation, and Player Identification Lead in January 2019, to brainstorm the applied implications for the batting findings, where implications for talent identification and talent development in cricket were produced. Following this, the Head of Science, Medicine and Innovation arranged to meet with the National Lead Batting Coach (Graham Thorpe) to receive feedback on the implications produced, and to utilise his playing and coaching experience, by requesting specific examples as to how the implications could be applied to practice.

- **Batting development findings working group – meeting #3:**

  The Head of Science, Medicine and Innovation met with the National Lead Batting Coach in February 2019, who provided feedback on the evidence-based implications, along with specific examples as to how the implications could be applied to practice. These will contribute to the Coach education video that will be produced in 2019 (*see* ‘PhD Impact and Dissemination: Overview’ section & Chapter 4 for more information).

Chapter 6

General Discussion

Summary of Results

This thesis aimed to identify and better understand features contributing to the development of expertise, and reveal the strongest precursors of expertise. To address these questions, machine learning (pattern recognition) techniques were applied to the microstructure of practice in a truly elite (super-elite) sample for the first time, protocols for benchmarking levels of expertise were developed to measure inter and intra-sport differences, and predictive and validated models of cricket expertise were subsequently produced.

The relative age effect (RAE) was initially examined in super-elite test cricketers and rugby union players. General findings revealed inter-sport differences; cricketers born earliest in the year (Q1) were overrepresented in the sample, whereas a reversal of this widely reported RAE was observed for all super-elite rugby union players, who were relatively younger (Q4). However, discipline/position specific analyses of RAE highlighted intra-sport differences, offering explanations pertaining to the ‘survival and evolution of the fittest’ concept. These differential findings led to a discipline-specific approach for examining expertise development in cricket. Furthermore, in order to better understand the truly multifaceted and complex nature of expertise, a holistic approach for measuring the predictive power of features was required.

Machine learning (pattern recognition) was identified as the optimal approach for holistically exploring the multifaceted and complex nature of expertise in cricket, and as such, was applied to examine the predictive power of discipline-specific feature subsets. This produced predictive models with validated classification accuracy for samples of elite vs. sub-elite spin bowlers, and super-elite vs. elite batsmen respectively. Notably, the amalgamation of contextual interference and variability theories with developmental histories enabled measurement of the influence of the nature and microstructure of practice activity in the development of batting expertise. The findings identify psychologically challenging skill-based practice, relatively early in development, as a catalyst for progression to super-elite expertise.

Furthermore, these discipline-specific examinations identified discriminating features between levels of expertise across developmental histories, encompassing early developmental experiences, quantities of domain-specific practice, competition experience, and adaptability to new levels of senior competition.

The central findings are discussed in relation to the domains of expertise development, forming theoretical implications, to complement the applied implications presented within each chapter.

Theoretical and Methodological Implications

The theoretical implications of the thesis will be discussed across three sections:

(a) Key discriminating findings which contribute *significant* knowledge to the field, representing a novel finding, and/or demonstrating consistency across thesis chapters.

(b) Discipline-dependent findings which are *contingent* on discipline/position.

(c) Commonalities, features which do not discriminate between the defined levels of expertise: equally *important* or equally *irrelevant* for the development of expertise?

(a) Key Findings

This subsection critically discusses the findings which advance understanding of expertise development most, as a direct consequence of either uncovering a novel finding, and/or through identifying consistent themes across the thesis chapters (offering most confidence in their importance).

Practice and Play

Domain-specific practice and play represent consistent findings across chapters three and four. Notably, the larger volume of more randomly structured practice with greater (maximum) variability undertaken by super-elite batsmen aged 16, represents the first empirical support for the learning benefits of the contextual interference effect and practice variability to the development of truly elite performers in the applied field. Super-elite batsmen's larger volume of general cricket practice, and play, aged 16, were also discriminating features, along with elite spin bowlers' greater proportion of spin bowling-specific practice up to age 14.

Quantity. Findings consistently replicated the existing strong and positive relationship between the quantity of domain-specific practice and sport expertise level (for a review *see* Baker & Young, 2014). However, contrary to previous evidence, there was no direct evidence to suggest that the greater quantities of practice were the result of earlier sport specialisation (Ward et al., 2004). Rather, this relationship appears non-linear within the thesis, whereby the wider findings reflect complex interactions between the cricketers' environmental factors, and underlying interpersonal characteristics (Baker & Cobley, 2013).

Despite no differences between the number of practice hours undertaken by elite and sub-elite spin bowlers up to the age of 14, a greater proportion of the elite's practice constituted spin bowling-specific practice. This higher quantity of spin bowling-specific practice could be a longstanding effect of their earlier regular involvement in cricket, and unsupervised practice. However, these earlier developmental experiences should not be mistaken for early specialisation; both spin bowling groups' comparatively late sport ($M_{\text{age}} = 16.73$) and discipline ($M_{\text{age}} = 13.86$) specialisation, appears more indicative of a diversified sporting and cricket development (Baker, 2003; Côté et al., 2007). Together, these findings support the conclusion that an interaction of early engagement in diverse-sports participation, with sport-specific practice/training, mostly facilitates the development of elite expertise (Güllich, 2018; Huxley et al., 2017, 2018).

The elite's discriminating spin bowling-specific practice up to age 14, spanning their formative years, demonstrates that spin bowling takes years of crafting to develop a repeatable action and/or consistent bowling outcomes, required for international cricket (Such et al., 2012). The proprioceptive benefit associated with early practice is deemed vital in the skill acquisition process, resulting in the reliable production of the necessary skills on demand (Masters, 2013). Undertaking *more* spin bowling-specific practice *earlier* is therefore likely to present lasting advantages for spin bowling dexterity. Consequently, the sub-elite's lower quantity of spin bowling-specific practice during early development, could have meant that they were unable to develop a repeatable action, or achieve consistent bowling outcomes.

The larger volume of cricket practice activity undertaken by super-elite batsmen aged 16, compared to the elite, represents the earliest practice-related feature to discriminate batsmen. The larger volume of practice undertaken by super-elite batsmen is consistent with the 'investment stage' advocated by the DMSP (Côté et al., 2007). Indeed, whilst it can be reasonably assumed that this practice is likely 'highly specialised', this finding does not advance our current understanding of the influence practice activity on the development of expertise, when considered in isolation. Although the super-elite undertook a larger volume of cricket practice aged 16, they also reported that a greater proportion of this volume consisted of activities which were "fun, voluntary, developmentally free from specific focus and provided immediate gratification" (Deliberate Play, Côté, 1999), as opposed to "effortful, focused, goal-directed and not inherently enjoyable" (Deliberate Practice, Ericsson et al., 1993). The greater volume of play undertaken by the super-elite aged 16, adds meaning to the super-elite's pre-existing (greater) practice quantity. Furthermore, the timing of this finding is intriguing, given how deliberate play was originally conceptualised as the foundational 'sampling stage' of development activity within the DMSP (age 6 to 12), whereas, the sampled batsmen were already attached to an organised cricket programme by the age of 16. These findings provide an indication of how best practice was structured but do not address the microstructure of practice activity in the development of super-elite expertise.

Microstructure of Practice. Our results speak to the microstructure of practice activity in the development of truly elite cricket batsmen, by amalgamating existing contextual interference and practice variability theories, whilst accommodating wider developmental experiences that have previously formed the focus of expertise research (e.g., age of specialisation) (Jayanthi et al., 2013).

At age 16, super-elite batsmen undertook a larger volume of batting skills-based practice that was more random, and more varied in nature, compared to the elite. The super-elite's more randomly structured practice is represented by the greater number of shots that they practiced in a random fashion. Variability of practice was categorised by three shot variations: the direction the ball was manoeuvred to; loft; and the pace generated off the surface of the bat. The super-elite applied greater (maximum) variations to their shots executed during random practice aged 16.

The most parsimonious explanation for this novel finding, relates to the superior long-term learning retention associated with higher contextual interference and variable practice (for a review *see* Monsell, 2003). Although highly random and varied practice is considered detrimental to performance during early skill acquisition, the increased challenge associated with its dynamic nature, suggests that its benefits are long-term, exhibited by the super-elite's durable level of expertise (Lin, Fisher, Winstein, Wu, & Gordon., 2008). This is grounded in research by Shea and Morgan (1979) which showed that practice incorporating high levels of contextual interference (random practice) led to better retention of the practiced variations in a motor skills task. Their results highlighted that high levels of contextual interference provide a means of eliminating dependency on reinstating the practice context for optimal performance. Therefore, whilst lower contextual interference (blocked practice) is likely fundamental for early acquisition, leading to superior short-term performance, the present findings showed that the super-elite's prolonged exposure to higher levels of contextual interference enabled successful transference to markedly challenging performance environments, suggesting contextual interference aided the long-term development of an adaptive schema (Brady, 2008;

Lawrence et al., 2014; Monsell, 2003; Pinder et al., 2011; Porter & Magill, 2010; Shea & Morgan, 1979).

The greater volume of dynamic, as opposed to static practice drills, undertaken by the super-elite aged 16, more closely replicates the coordination patterns representative of competitive performance, and likely produced long-term skill retention and replication benefits (Wilson, Simpson, Van Emmerik, & Hamill, 2008). Consequently, this supports the notion that the constraints of training and practice during development should replicate the performance environment, to allow learners to detect affordances for action and couple actions to key information sources within those specific performance settings (Representative Learning Design, Brunswik, 1956; Pinder et al., 2011).

The superior predictive power offered by combining (higher) contextual interference and practice variability offers a 'deliberate' practice framework for expertise development in sport, representing 'domain-specific' practice, and provides a mechanism for optimising challenge (Ericsson et al., 1993; Guadagnoli & Lee, 2004). This finding bridges the limited context specificity posed by deliberate practice theory's conceptualisation within a music setting, and its application potential for sport (Ford, Coughlan, Hodges, & Williams, 2015). The findings refute the necessity of 10,000 hours for developing expertise, and instead appear indicative of the moderating function of the microstructure of practice in the monotonic benefits relationship (Ericsson et al., 1993; Ford et al., 2015; Tucker & Collins, 2012).

Super-elite batsmen's greater volume of cricket play, and more random and varied practice aged 16, presents a new dimension to deliberate practice and deliberate play theories, given how play is conceptualised within the 'sampling stage' of a child's development, and suggested to dissipate post-age 15 (Cotè et al., 2007; Ericsson et al., 1993). Moreover, this finding presents a challenge to the original conceptualisation of deliberate practice, in light of the evidenced crossover between the volumes of cricket play and random-variable (‘deliberate’) practice, which highlights that cricketers’ perceptions of these activities are not dissimilar. Deliberate practice is partially defined as being an activity that provides no “inherent enjoyment”. This description appears overly simplistic, as it automatically implies that practice activity which evokes enjoyment is not ‘deliberate’. It might be suggested that activities which meet the current needs of performers are more likely to evoke feelings of enjoyment and satisfaction; random and varied practice is challenging, but necessary.

The present findings suggest that the definition of deliberate practice should be modified, to be applicable to a sporting expertise context. Restricting the definition to the nature of practice activity undertaken, rather than referring to the enjoyment or satisfaction evoked from the activity, would serve to better differentiate deliberate practice from deliberate play. The suggested modification reflects the fact that the super-elite enjoyed their random and variable practice, which may be partly due to a specific mindset and/or a personality disposition.

A performer who exhibits the characteristics of a growth mindset, and who is self-regulated, will have the ability to engage and persist in tasks that are not inherently motivating or interesting, but nevertheless important for development. This could explain why the super-elite appear to enjoy the more challenging random and variable practice undertaken (Dweck, 2008; Petlichkoff, 2004). Additionally, the prominence of certain psychological characteristics including commitment, self-confidence, work ethic, resilience, determination and sacrifice supports previous research of expert performers (Holt & Dunn, 2004; Weissensteiner, Abernethy, & Farrow, 2009). The study of personality traits of Olympic athletes has revealed that super-elite athletes have a greater need to achieve, demonstrate greater ruthlessness and selfishness, and possess higher levels of obsessiveness and/or perfectionism, in the pursuit of their training and performance goals, discriminating them from elite athletes (Hardy et al., 2013, 2017). It is conceivable that these traits were exhibited in the super-elite batsmen and elite spin bowlers' discriminating training and performance behaviours, who between them, experienced a pronounced diversified youth sport engagement, prolonged extensive sport-specific practice and competitions, and continued their performance improvement over more years during adulthood, to achieve mastery (Güllich et al., 2019; Hardy et al., 2013, 2017).

The lack of observable performance indicators identified during cricketers' early development presents challenges for talent identification accuracy, particularly for performance-orientated programmes. This is especially true for elite spin bowlers, whose actions *outside* of competition, distinguished them from sub-elite bowlers, during the initial stages of development. For super-elite batsmen, competition-based features do not discriminate until age 18. Instead, their earlier developmental discriminators reflect the optimisation of challenge, which is suggested to translate into superior long-term performance (Ericsson et al., 1993; Guadagnoli & Lee, 2004; Henry, 1968; Lin et al., 2008; Pinder et al., 2011). This finding extends the conclusions of previous studies of cricket and wider sport, where future potential cannot usually be predicted accurately using traditional age-group performance measures alone (Barney, 2015; Kearney & Hayes, 2018). This outlook suggests that a holistic approach is required to more accurately identify talent, by recognising the contribution of psychological and social development, alongside performance-related features, within the multifaceted nature of expertise.

To the best of our knowledge, no empirical study has previously developed and applied a quantitative method to measure the microstructure of practice activity among truly elite sportspeople. The sheer number of discriminating features across both the quantity *and* microstructure of practice activity represents a significant advancement to knowledge of expertise development. Consequently, the literature is better placed to describe desirable practice environments, by addressing '*what*, *when* and *how'* one should practice. Discussion of the remaining key findings which contribute significant knowledge to the field, will advance our understanding of the multifaceted nature of expertise.

Adaptability

Findings emerging from chapters three and four highlight the superior adaptability of elite and super-elite cricketers, upon progressing to new levels of senior performance. Elite spin bowlers demonstrated superior adaptability throughout senior cricket competition representation, by firstly achieving a significant performance in senior club and Second XI county cricket sooner than the sub-elite, following debut. Upon progressing to First XI County Cricket, elite spin bowlers establish themselves sooner, to become the best spin bowler in their respective teams in fewer years. Super-elite batsmen's superior adaptability is more gradual, as they establish themselves sooner than the elite by: becoming the best batsmen in their Second XI team in fewer years; becoming one of the best batsmen in their First XI team in fewer years; being more likely to become the best batsman in their First XI team (outright); and becoming the best batsman in their First XI team in fewer years.

The findings highlight discipline differences in the nature and timeline of the cricketers' superior adaptability. The timing of elite spin bowlers' emerging superior competition-based adaptability, first demonstrated in senior (amateur) club cricket during their early teens, could conceivably be heavily influenced by innate factors, enabling short-term adaptability, known as the "initial performance effect" (Helsen et al., 2005). However, the present findings suggest that the interaction between elite spin bowlers' earlier discriminating features more accurately explains their subsequent development of expertise, evidenced by their earlier regular involvement in cricket, earlier uptake of unsupervised cricket practice, and greater quantity of spin bowling-specific practice up to age 14. These developmental experiences gradually transcend into greater adaptability, as the elite become the best spin bowlers in their respective county teams. By this time, the (prospective) elite spin bowlers possess the skills to thrive, in the face of increasing physical, psychological and technical demands of international cricket.

Super-elite batsmen's superior adaptability is first observed within senior county cricket, indicative of gradual adaptability. The absence of superior short-term performance-related adaptability suggests that the weighting of developmental histories could be greater in batsmen than spin bowlers, in the overall attainment of expertise. The absence of short-term indicators of adaptability, against the presence of more gradual indicators of adaptability, reinforces the *long-term* skill retention benefits of higher contextual interference and variability within the development of super-elite batsmen (for a review, *see* Brady, 2008; Monsell, 2003). Elite spin bowlers' superior short-term adaptability occurred *in spite of* the patience and resilience to fully develop the qualities required to deceive batsmen, suggesting that superior short-term adaptability is an indicator of long-term spin bowling potential (Such et al., 2012).

Elite spin bowlers' evidenced short-term (performance-related) adaptability may explain the absence of short-term adaptability for batsmen, given how the disciplines are in direct competition with each other. Furthermore, this finding could be partly indicative of the relative rate of development for each discipline, where batsmen's early potential is realised more gradually, and spin bowler's early potential can be observed in performances during their early teens; elite spin bowlers' early superior adaptability during competition could provide a challenge that triggers super-elite batsmen's latent superior adaptability. Overall, the superior adaptability shown across the disciplines demonstrates that, the higher the level of competition, the more gradual prospective international cricketers' (superior) adaptability becomes, reflected in the longer time taken to adapt to senior county cricket.

Adaptability, and subsequent transition across levels of performance, are relatively short-term development outcomes, within the long-term development of expertise, whose underlying mechanisms likely reflect an interaction between developmental and genetical features (Baker & Cobley, 2013; Tucker & Collins, 2012). However, the translation of superior adaptability into international representation, suggests adaptability is a durable indicator of long-term potential in cricket. This revelation carries implications for both talent identification and development, as the relationship between youth success and senior success may not be as weak as previously identified (e.g., Kearney & Hayes, 2018). Rather, elite spin bowlers' development suggests that this relationship is contingent on *how* success in performance is measured, emphasizing the importance of evidence-based discipline KPI's.

The absence of short-term performance indicators of adaptability for batsmen also suggests that the conversion of batting potential into super-elite expertise is complex. This reinforces the need to identify durable attributes, meaning that officials should invest most resource into maximising batsmen's early development experiences. The higher contextual interference, indicated by the super-elite's larger volume of more random and variable practice aged 16, suggests that they persisted in the wake of these challenges, despite the associated early performance decrements. Thus, the early performance decrements, and longer acquisition time, may partially explain the absence of superior short-term performance-related adaptability for the super-elite. However, they thrived under more challenging circumstances in the medium to long-term, shown by their quicker transition across senior levels of competition, and superior adaptability at these levels, compared to elite batsmen. Early exposure to rivalry and competitiveness, from engaging in competitive play-related activities with older siblings, likely fostered resilience in the super-elite, equipping them to cope with high-level challenges from an early age (Hopwood et al., 2015; MacNamara, et al., 2010).

The present subsection of findings advances our understanding of the probable contributing features to the superior adaptability shown by elite spin bowlers and super-elite batsmen, alongside the wider impact of adaptability on the subsequent development of expertise. Further work is required to better understand the underlying mechanisms of adaptability, to enable the structuring of environments which foster adaptable behaviours. All considered, these findings demonstrate how optimising challenge at both a psychological and technical level, is likely a catalyst for progression to super-elite expertise.

Competition Quantity

Differences in cricket competition experience make up a sizeable proportion of the discriminating features across the disciplines. Elite spin bowlers experienced a larger volume of competition than the sub-elite, by their international debut ($M_{\text{age}} = 24$). Furthermore, the elite cumulatively bowled a larger proportion of their teams' overs across competition representation levels, up to their First XI County debut, compared to the sub-elite. Super-elite batsmen experienced a larger volume of competition than the elite aged 21 and 22, the two years preceding their international debut ($M_{\text{age}} = 23$).

There are at least two possible overarching interpretations for the present findings. Firstly, performers may benefit from the increased competition experience, gained by being selected more frequently from an earlier age (Jones et al., 2018). The constant replication of skills is suggested to facilitate the development of robust technique, resulting in the reliable production of the necessary skills on demand; this may have enabled cricketers to later thrive under the marked demands of international competition (Masters, 2013; Shea & Morgan, 1979). Alternatively, performers could be selected for competition more frequently on the basis that they possess superior ability and/or higher potential. The development trajectories of the cricketers sampled suggest that the explanation is probably discipline-dependent.

Elite spin bowlers experienced greater competition experience up to their international debut. Whilst they could conceivably have not necessarily performed well, the evidence refutes this. Instead, it is likely that their more frequent selection reflects the elite's (sustained) superior ability, compared to the sub-elite, best described by the elite's larger proportion of overs bowled, and achievement of an earlier first significant performances, upon transitioning through the talent pathway. The elite spin bowlers' higher ability is most likely partly owing to the earlier discriminating developmental experience previously outlined. However, the elite will have likely gained some benefit from greater competition experience at an earlier age, which may have been a contributing factor to their subsequent regular selection for competition. In contrast, volume of competition does not become a discriminating feature for super-elite batsmen until they have entered senior county cricket. The super-elite's gradually demonstrated superior ability is consistent with the long-term learning benefits of their highly dynamic and challenging representative practice, extending the specificity of practice principle, and promoting implicit learning (Henry, 1968; Lawrence et al., 2014; Masters et al., 2008; Pinder et al., 2011).

(b) Discipline-dependent Findings

The Relative Age Effect

The relative age effect (RAE) was initially examined in a worldwide sample of super-elite test cricketers and rugby union players in chapter two. General findings revealed inter-sport differences; cricketers born earliest in the year (Q1) were overrepresented in the sample, whereas a reversal of this widely reported RAE was observed for rugby union players, who were relatively younger (Q4). Upon closer examination, the Q4 RAE reversal was also observed for rugby union forwards, whereas the widely reported Q1 RAE was evident for rugby union backs, and cricket batting and spin bowling disciplines; no RAE was found for the pace bowling discipline. The RAE was subsequently examined in chapters three and four, as part of holistic examinations of expertise development in English cricketers, revealing that elite spin bowlers were born later in the year (typically Q3), whereas no RAE was found for the super-elite batsmen sampled. These findings add to the dearth of research examining the prevalence of RAEs in super-elite performers (i.e., Grondin & Trudeau, 1991).

The rigorous methodological design, and novel findings of chapter two, measuring RAEs in worldwide super-elite sportsmen, set the precedent for the thesis on multiple fronts.

Firstly, the developed stringent criteria to benchmark level of expertise was subsequently applied across all studies, to ensure that emerging findings were not because of inconsistent or unclear benchmarking (Coutinho et al., 2016). Secondly, the chapter's consideration of unique inter and intra-sport requirements enabled comparison of the unique physical, technical and cognitive differences between positions/disciplines, despite neglecting the multifaceted nature of expertise; this has advanced understanding by allowing for discussion of the (potential) explanations for the differential RAEs. Overall, the study findings led the authors to conduct discipline-specific investigations of wider expertise domains, encompassing birth quarter comparisons, in samples of cricket batsmen and spin bowlers, to determine their overall contribution in the development of expertise. The development of robust super-elite criteria in the thesis provides confidence that the effects of the super-elite's developmental experiences are durable, enabling advancements to RAE research.

Physical attributes do not represent the highest weighted desirable characteristics of international cricketers, compared to psychological and skill-based competencies (except for the pace bowling discipline), despite the early Q1 selection bias observed across junior cricket pathways (Barney, 2015). This could lead to a relatively constant composition of cricketers progressing from junior to senior level. As such, the findings in chapter two suggest that the greater the emphasis placed on physical characteristics in a given sport, the less likely the Q1 RAE will extend from junior to senior level, due to the ongoing developmental potential of Q4 born players. Equally, the less weighting is placed on physical characteristics, the more likely the Q1 RAE will transfer to senior level.

The absence of a RAE for the pace bowling discipline (a discipline contingent on both physicality and technique), shows that neither of the 'survival and evolution of the fittest' concepts sufficiently explain the development of expertise in all sports and disciplines. Consequently, a holistic approach, that better represents the complex nature of expertise development in cricket was required, to incorporate understanding of the interactions between wider developmental histories. It was this realisation that provoked further investigation of precursors of expertise, to identify the features that contribute towards the multifaceted nature of cricket expertise.

Subsequent examinations of the development of cricket expertise confirmed that the attainment of expertise is more comprehensively and accurately explained through holistic examinations of expertise domains, and the features contained within them. This holistic approach measured the multifaceted and complex nature of expertise, enabling further scrutiny of the validity of explanations pertaining to the ‘survival and evolution of the fittest’ concepts.

Discussion of potential underlying mechanisms of RAE, alongside the discriminating developmental experiences of elite performers, has identified consistent overlap between the explanations provided for the differential RAEs observed across disciplines/positions, and the developmental trajectories undertaken by the elite and super-elite. The wider examination of the developmental histories of elite and sub-elite spin bowlers in chapter three, revealed that elite (international) spin bowlers were more likely to the born later in the year, compared to their sub-elite counterparts (~Q3 born vs ~Q1 born). This presents an alternative finding to the Q1 RAE observed in a worldwide sample of super-elite spin bowlers (Chapter 2). The wider developmental discriminators identified in chapter three indicated that elite spin bowlers in England were subjected to foundational challenging development experiences, where their subsequent success is indicative of both the ‘survival *and* evolution of the fittest’ concepts. The dexterous nature of spin bowling presents inherent challenges, meaning that technique must be developed over time, with findings suggesting that pre-age 14 experience is of upmost importance. In addition, prospective elite spin bowlers must remain viable by demonstrating their long-term potential; requiring spin bowlers to adapt quickly to competition, and develop resilience from these experiences, enabling coping and thriving when facing future challenges

(MacNamara et al., 2010). These experiences suggest an interplay between desirable developmental challenges posed by surviving, and those encountered when evolving to become an elite (international) spin bowler, illustrating the overarching importance of the developing spin bowlers' environment.

Whilst there was no evidence of RAEs among the chapter four's study of the developmental histories and practice biographies of English super-elite batsmen, the study provides support for the existing explanation pertaining to the 'survival of the fittest' concept, attributed to the Q1 RAE observed for super-elite batsmen worldwide in chapter two. The concept outlines that Q1 born batsmen likely benefited from prolonged exposure to desirable development experiences, having probably been attached to a cricket development programme from an early age, in light of widespread Q1 RAE junior selection bias. There is no evidence in chapter four to refute the suggestion that English super-elite batsmen were also attached to a cricket development programme at the earliest opportunity. Moreover, the study identified that development and practice experiences indicative of optimising challenge were most common in super-elite batsmen, discriminating them from elite batsmen sampled. However, performance-related markers of potential were not apparent until senior levels of cricket competition, suggesting that batsmen may initially need to survive, in the wake of these (self-driven or imposed) earlier challenging developmental experiences, before they are able to demonstrate their (long-term) potential in competition, and evolve to become successful international batsmen.

In summary, the 'survival of the fittest' concept likely reflects a performer's psychological capacity to deal with the challenges associated with their sport in the context of their developmental trajectory. The 'evolution of the fittest' concept likely represents the successful interaction between a performer's psychological capacity, and their developmental experiences, from which an 'optimal' interaction could result in the development of elite expertise. Given that development of expertise is non-linear, with multiple routes to the top, this could mean that performers require a stronger psychological profile to mitigate a less effective development environment, or vice versa. Equally likely, some disciplines/positions possess inherent challenges, such that an optimal equilibrium between psychological and development capacity (potential) is needed for development of the highest expertise, e.g., cricket spin bowling. The discussion argues that incorporating pathway and discipline/position-specific longitudinal examinations of RAE prevalence will lead to a better understanding of its overall influence in the development of expertise. Future studies should incorporate measures of RAE among multifaceted studies of expertise development, to enhance understanding of the extent of its contribution to performers' development.

(c) Commonalities: Equally *Important* vs. Equally *Irrelevant*

The primary aim of the thesis was to determine the developmental features that discriminate between differing levels of cricket expertise. A total of 721, from the 751 (96%) features collected and analysed across the thesis, represent commonalities between the relatively synonymous levels of expertise. These features are reported as precursors within the expertise literature, and as such, the sheer number of commonalities identified raises an important discussion point. These commonalities include: internal and external focus of attention; prescriptive and constraints-based learning; methods of conveying information; intrinsic and extrinsic feedback; and early and late specialisation in a sport/discipline (Hodges & Ste-Marie, 2013; LaPrade et al., 2016; Sigrist et al., 2013; Wulf, 2013). There are (at least) two reasons for why the present dataset likely contains commonalities possessing equal importance to the discriminators, in the overall development of expertise. Firstly, several of the commonalities appear as discriminators at different stages of development, and reappear as commonalities for the remainder of cricketers' development. For example, the volume of random and variable practice are commonalities at ages 18 and 22, despite discriminating at age 16. The data shows that all batsmen undertook *some* random and varied practice post-age 16, which could be a necessary activity for all batsmen, to maintain relative performance level beyond adolescence. Secondly, there likely exist commonalities across cricketers' development which are necessary for early development, rather than being discriminating features between expertise levels. In this regard, blocked practice has been suggested to help facilitate initial acquisition (known as the cognitive or verbal-motor stage of learning), as it is difficult for subjects to determine the appropriate strategies when faced with random contexts (Fitts, 1964; Fitts & Posner, 1967; Shea, Kohl, & Indermill, 1990).

Commonalities identified as being equally irrelevant in the development of spin bowling expertise (*see* Chapter 3) could represent 'red herrings', given how researchers have persistently examined these domains of expertise across differential levels of sporting expertise. This suggests that bias among researchers and sport officials (Baker et al., 2018; Wattie & Baker, 2018), has led to 'unshakeable faith' in some avenues of exploration, reflecting confirmation bias (Wason & Jonhson Laird, 1972). As such, this likely means that expertise domains with otherwise strong(er) predictive potential have been overlooked historically, such as the microstructure of practice; previously unexplored in a truly elite sample, but identified as a precursor of super-elite expertise in the present thesis. The findings demonstrate how existing methodological limitations, including confinement to one-dimensional studies of individual expertise domains, and a reliance on linear analysis techniques, can lead to a misrepresentation expertise development, by disregarding the multifaceted nature of expertise (Mann et al., 2017; Schorer & Elfering-Gemser, 2013).

Future expertise development research must strike an optimal balance between formulating research that is both context-specific, and rigorous, to overcome the systematic issues noted. The thesis developed a method to bridge the perceived gap between research and applied practice, by firstly collaborating with pathway officials, to understand the performance priorities in cricket, and arrive at an optimal solution for all involved; a context-specific research design which employed machine learning techniques to address a pathway-specific problem, and led to the subsequent delivery of pathway-specific insights, with several implications for the development of wider expertise in sport.

Strengths and Limitations

Limitations

There are a number of empirical limitations relating to the thesis research design. Firstly, the work is centred on retrospective methods. The interpretations of the cross-sectional examination of RAE prevalence in chapter two were based on assumptions regarding performers' initial presence in the junior pathway, and subsequent transition across competition levels, prior to becoming super-elite, however these were not directly measured. That said, whilst speculative in nature, the explanations offered reflect the summation of knowledge from the plethora of research that has explored RAE prevalence. There are several other methodological issues associated with the thesis; the developmental history of cricketers, explored in chapters three and four, are centred on self-reported, retrospective accounts of development. The questionable reliability of retrospective recall, and a lack of specificity in questions present limitations to research exploring developmental histories, particularly surrounding performers' reporting of average practice and competition times (Hopwood, 2013). These issues represent potential major problems to the design of research across the expertise development landscape, and the absence of a validation study of the interview framework means that it can only be assumed that these concerns are shared in the thesis. That said, investigations of super-elite performers' demographics, practice quantity, and performance-related milestones have been validated within the Great British Medallists study, which triangulated athlete data with parent and coach responses (Güllich et al., 2019; Hardy et al., 2013, 2017). Moreover, numerous strategies were applied to preserve the reliability and validity of the measures adopted across the thesis, which are expanded upon within the empirical chapters. The strategies reflect what were considered practical, and necessary, in mitigating the risk of confounding variables in the thesis findings, and within the constraints of the research programme, e.g., the development of a matched pair design (Hardy et al., 2017; Güllich et al., 2019). The interpretation attached to the thesis findings are theoretically driven, but largely speculative because of the descriptive nature of the thesis research design. Whilst these interpretations reflect the candidate's understanding of contemporary research in the field of expertise development, there are likely other fruitful explanations for these findings, such as dynamical systems theory (Davids, Glazier, Araujo, & Bartlett, 2003). An extension of the mixed method approach employed in chapter three, would have enabled expansion on findings, to aid interpretation, and reduced conjecture across the thesis, particularly surrounding the developmental challenges identified.

Strengths

There are several strengths to the thesis. From a theoretical perspective, the thesis has overcome numerous overarching limitations of previous research, amalgamating individual domains of expertise, previously studied in isolation, into single holistic studies of expertise development, to measure the multifaceted and complex nature of expertise. This includes being the first study in the field to develop and apply a measurement to quantitively measure the influence of the microstructure of practice in a truly elite sample, providing a template for researchers to begin validating existing lab-based expertise development research in the field.

The holistic approach enabled a thorough general discussion, drawing theoretical links between multiple domains of expertise. For example, the present findings have demonstrated that the microstructure of practice could moderate the volume of practice necessary for the development of expertise. Furthermore, discipline-specific explorations have led to the identification of differences in the nature and timeline of batsmen and spin bowlers' superior adaptability, identifying durable indicators of long-term potential. The investigation, and discussion of the RAE among wider development has brought the discipline closer to understanding the function of RAE within the development of expertise, attaching a conceptual framework to the ‘survival and evolution of the fittest’ concepts, first introduced in chapter two. The development and application of a set of stringent criteria to benchmark levels of expertise across all studies represents a further strength of the thesis.

The thesis overcomes the limitations of linear analytical approaches typically adopted in expertise development research, applying non-linear machine learning (pattern recognition) techniques, to identify the optimal feature subsets that possess greatest predictive power, in discriminating between levels of expertise. Machine learning-based study designs are fallible in the absence of a model’s ‘validation’, where the generalisability performance of a trained predictive model is tested on an ‘unseen’ sample (Kuncheva & Rodriguez, 2018); this issue was recently highlighted in the UK national media (Ghosh, 2019). The necessity for model testing presents a hurdle to the sport science discipline, which typically relies on special populations, and as such, is constrained by modest sample sizes and/or limited access. Test datasets were successfully sourced for the present research, in spite of these constraints. The testing samples were modestly sized, ranging between 18 to 30% of the model training datasets, however they were maximised within the bounds of the cricket population that met the criteria. The excellent accuracies obtained from the model testing offers direct application to the ECB’s talent pathway, demonstrating that homogeneity within populations is not a necessary assumption for pathway-specific research involving elite performers.

Future Research Directions

The thesis has advanced theoretical understanding of expertise development, by identifying strong precursors of expertise, leading to the refinement of the ECB’s current talent pathway processes, including methods for benchmarking expertise and profiling youth cricketers. Prospective research would determine whether these retrospective findings stand the ‘test of time’, advancing our knowledge further. Moreover, this generation-specific research design would address the limitations associated with recall (Côté et al., 2005; Helsen et al., 1998; Hopwood, 2013; Ward et al., 2004).

Examinations of expertise attainment could be strengthened, by widening investigations to encompass physiological, psychological and social features, alongside the nature and microstructure of practice, and developmental experiences, to measure the multifaceted nature of expertise more comprehensively (Abernethy, 2013; Güllich et al., 2019; Rees et al., 2016). The supervisors of the present research programme felt that this breadth of investigation would be excessive for the workload of a single PhD student.

Researchers must be adaptable in their means of collecting and analysing rich datasets, to accurately capture, and represent the truly dynamic nature of expertise within research designs (Baker et al., 2018; Mann et al., 2017). In this regard, the use of mixed methods, drawing on the non-linear analytical capabilities and exploratory qualitative techniques, would lead to a more comprehensive understanding of expertise attainment in future research (Amartunga, Baldry, Sarshar, & Newton, 2000; Güllich et al., 2019; Hardy et al., 2013; Mann et al., 2017; Poczwardowski, Barott, & Jowett, 2006). While analytical capabilities are expanding within the sport science discipline, quantitative data collection should continue to be underpinned by empirical evidence or theory, and be subjected to robust ‘feature selection’ methods to guard against the risk of type 1 errors (Güllich et al., 2019; Kuncheva & Rodriguez, 2018; Newman & Pearson, 1928, 1933).

RAE research would benefit most from pathway-specific, prospective examinations of prevalence, to determine the conversion rates of player progression and deselection, to enable more precise explanations of the impact of RAE on development (Chapter 2: Jones et al., 2018). Furthermore, examination of the reported underlying processes/mediating factors of RAE (including sport age, maturation, resilience and mental toughness), amongst wider (holistic) approaches, will advance understanding of the RAE's function in the overall development of expertise (Bell et al., 2013; Collins & MacNamara, 2012; Jones et al., 2018; MacNamara et al., 2010; McCarthy & Collins, 2014; McCarthy et al., 2016).

The thesis has demonstrated the importance in developing robust criteria to classify levels of expertise, to improve the reliability of findings across the research landscape (Baker et al., 2015; Coutinho et al., 2016; Swann et al., 2014). Expanding the number of expertise classes (comparison groups) found within expertise research, limited to two within the present thesis, will lead to greater understanding of the differential influence that precursors possess at different levels of expertise. This expansion would reduce the need for dichotomy in the classification of expertise, and reduce conjecture surrounding the relevance/irrelevance of non-discriminating features (Chapter 3; Chapter 4; Güllich et al., 2019).

Comparison groups must also remain relatively synonymous. By this, analysis must discriminate between super-elite and elite, or those that 'make-it' and those that just fail to make-it, across different levels of expertise, rather than using polemic player groups. This presents a statistical challenge, with the relatively small participant numbers that 'make it' to the highest levels of achievement. Standard statistical processes, such as, linear discriminant function analyses, are constrained by small sample sizes and non-linearity (Fukunaga, 1990; Tharwat, Gaber, Ibrahim, & Hassanien, 2017). These restrictions present a major problem to the sport science discipline, where sample sizes are most common, and the developmental journeys of elite performers are described as non-linear (e.g., Collins, MacNamara, & McCarthy, 2016; Hardy et al., 2017; McCarthy & Collins, 2014). It is therefore necessary for future expertise development research to adopt machine learning methods, which are most appropriate for interrogating "wide" datasets, and possess non-linear capabilities (Bishop, 2006; Güllich et al., 2019; Kuncheva & Rodriguez, 2018).

Succeeding in challenging circumstances represents a key attribute of elite performers, whether relating to the overall, long-term challenges of development, or short-term challenges presented, by transitioning to higher levels of performance, for example. Resilience facilitates coping and thriving under challenging conditions, however, the extent to which resilience originates from an interaction between innate features, compared to developmental experiences, amid adversity, is less well understood (Bell et al., 2013), and is a priority question for future research, carrying significant implications for talent identification and development (for a review, *see* Fletcher & Sarkar, 2013).

The conclusion of an ongoing 10-year longitudinal programme will lead to the validation of a talent identification model in cricket, aligned to the ECB's talent pathway. The programme assesses the discriminant and predictive value of age-group battery testing, and wider talent identification measures utilised in cricket (scouting and competition performance statistics), and will also provide an indication of the validity of age-group prediction across sport. The project, initially developed during Dr Ed Barney's PhD research programme (2015), was restricted to a cross-sectional research design, providing preliminary findings. I have project managed the programme since enrolling on my PhD studentship in 2014, forming a considerable proportion of my contracted part-time work with the ECB each year. The programme is the first of its kind known across sport, and can be most closely compared to the NFL combine, but instead involving junior cricketers ("NFL Combine", 2019). To date, I have collected, collated and analysed data of three year groups collected from 2011, and delivered preliminary conclusions to ECB pathway officials. These findings were not included in the thesis, given that the project is two years from its conclusion. The ECB have demonstrated a desire for me to continue this project, the findings of which will be published in due course (*see* Chapter 5 for information on the impact and dissemination of this work).

Personal Reflections

Arriving at the ECB's National Performance Centre in August 2014, as a very nervous graduate, to observe the pinnacle tournament of domestic age-group cricket, not only opened my eyes to the exceptional research opportunities that lay ahead, but also the unceasing support to match. This was summed up in my first encounter; greeted by Andy Flower, formerly Head Coach, who shook my hand and welcomed me to English cricket. This sentiment was to paint the picture of the great collaborations and friendships that I would form over the next 4 years.

I have a lot to thank Mo, Eddie, Courty, Brunchy, and Alun for, who believed in me, and embraced the research, and are part of the reason that the PhD programme has turned out to be a success for all involved. I am extremely fortunate to have interviewed England's greats, meeting the person behind the media persona, and learning of their development experiences, and sacrifices made to become the best. Even more fortunate, when I consider that my closest ally during the initial stages, was in fact 'Cricket for Dummies' (Knight, 2013).

The research process has led me to contemplate the perceived divide between theory and applied practice. The PhD has benefited from the insights of both, rather than relying on one approach over the other. My contracted applied days facilitated this, which is reflected in the overall impact of the research (Chapter 5). On reflection, this experience highlights the importance of developing 'meaningful' relationships with pathway coaches and practitioners, for the success of applied research projects. In my case, this involved taking the time to observe their environments, to understand the performance priorities, where I later gained trust and 'cricket credibility'. This process naturally led to some thoughtful conversations about utilising research to overcome performance problems, and was integral to the designing of this pathway-specific research, and production of pathway-specific findings. The collaborative nature of the PhD is evidenced by the fact that just one study contained in the PhD was originally included in the contracted research programme. I am very fortunate that my first experience of applied research was in collaboration with Peter Such, National Lead Spin Bowling Coach, who shared my enthusiasm and drive for the project to be a success.

Research containing small sample sizes of ‘extreme’ populations, with a far greater number of features than participants, appears at odds with the traditional research model. However, generalisability of findings can be addressed more directly than the confidence intervals traditionally used to predict generalisability performance. This is because the limited sample sizes allow generalisability to be maximised, by testing research findings against the *whole* sample relevant to the population being studied.

I end the PhD with an abundance of experience that I could have never imagined possible as an Undergraduate student of five years ago. I am extremely grateful for the opportunity first given to me by Bangor University and the ECB, against the odds, and I hope to continue this collaboration, as part of my next adventure.

Thesis Conclusion

A holistic method was developed to investigate the multifaceted and complex nature of expertise, by examining the influence of the nature and microstructure of practice, alongside wider developmental domains, in the overall development of cricket expertise. The research advances overall understanding of expertise development, by most notably quantifying the microstructure of practice for application in the field, within a sample of truly elite (super-elite) sportsmen. This approach employed non-linear machine learning (pattern recognition) techniques to identify the optimal predictive subsets that contained only the strongest precursors of expertise, demonstrating very good to excellent classification accuracy between the relative synonymous levels of expertise, and provides an effective means of interrogating 'wide' datasets within the sports science discipline.

The thesis findings suggest that early challenging skill-based, and psychological-based experiences in development, is a catalyst for progression to super-elite expertise. Specifically, combining the scheduling of random and variable practice relatively early in development, and gradually increasing contextual interference and volume, facilitates the optimisation of challenge for cricket batsmen. This finding offers a sport-specific conceptualisation of deliberate practice for developing expertise. Furthermore, the demonstration of superior ability, upon transition to heightened performance environments, is durable; the achievement of a combination of short-term and gradual performance milestones represents a strong precursor of expertise across the cricket disciplines. The findings support the earlier proposition that the inter and intra-sport differences observed in RAE prevalence reflect the unique psychological profile and development experiences necessary for expertise attainment. The external validity of the predictive models is evidenced by the 100% testing accuracy observed, offering direct application to the ECB's national talent pathway, and promise for the development of wider sporting expertise.

"Life can only be understood backwards; but it must be lived forwards." - Soren Kierkegaard

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Supplementary Information: Chapter 2

New evidence of relative age effects in 'super-elite' sportsmen: a case for the survival and evolution of the fittest

The aim of this supplementary document is to present:

1) Additional evidence pertaining to the 'Method' section contained within the manuscript, to further assist with future replication.

2) The raw data (quarter frequency distributions) of both studies.

1) Method Information

International Teams Sampled Within the Study

Study 1 – Cricket:

Australia

Bangladesh

England

India

New Zealand

Pakistan

South Africa

Sri Lanka

West Indies

Study 2 – Rugby Union:

Argentina

Australia

England

France

Republic of Ireland

New Zealand

Samoa

Scotland

South Africa

Wales

2) Quarter Frequency Distributions

Study 1

Table. Quarter distribution frequencies of cricketers across super-elite criteria and discipline groups

Criterion of Super- Elite	Disciplines	Q1	Q2	Q3	Q4	χ^2
Top 30 last 20 years	All Disciplines	**79**	64	47	72	7.36
	Batsmen	**37**	33	28	35	1.34
	Bowlers	**42**	31	19	37	9.25*
	Pace Bowlers	28	21	10	**30**	11.00**
n = 262	Spin Bowlers	**14**	10	9	7	2.60
Top 30 last 20 years; held highest rank > 1 month	All Disciplines	**36**	23	17	22	7.20
	Batsmen	**14**	10	10	4	5.35
	Bowlers	**22**	13	7	18	8.41*
	Pace Bowlers	**15**	9	4	14	7.31*
n = 98	Spin Bowlers	**7**	4	3	4	2.01
Top 30 last 20 years; minimum 50 international Test matches	All Disciplines	**44**	25	28	28	4.05
	Batsmen	**25**	20	21	18	0.67
	Bowlers	**19**	5	7	10	11.20*
	Pace Bowlers	**14**	3	3	9	11.68**
n = 125	Spin Bowlers	**5**	2	4	1	3.32
Top 30 last 20 years; spent 5 > years in top 30	All Disciplines	**32**	19	20	21	4.78
	Batsmen	14	12	**15**	8	2.35
	Bowlers	**18**	7	5	13	9.44*
	Pace Bowlers	**12**	4	3	11	8.66*
n = 92	Spin Bowlers	**6**	3	2	2	3.31
Top 30 last 10 years; spent 1 > month in top 30	All Disciplines	**60**	48	36	49	5.57
	Batsmen	**27**	24	20	26	1.18
	Bowlers	**33**	24	16	23	6.09
	Pace Bowlers	**20**	16	10	19	3.74
n = 193	Spin Bowlers	**13**	8	6	4	5.78
Top 30 last 10 years; spent 3 > years in top 30	All Disciplines	**36**	26	24	17	7.17
	Batsmen	**17**	13	15	6	5.39
	Bowlers	**19**	13	9	11	4.31
	Pace Bowlers	**13**	7	5	10	4.20
n = 103	Spin Bowlers	**6**	**6**	4	1	3.94

Top 20 last 20 years	All Disciplines	**58**	54	36	56	6.63
	Batsmen	25	**32**	24	28	1.43
	Bowlers	**33**	22	12	28	10.23*
	Pace Bowlers	22	16	8	**23**	8.28*
n = 204	Spin Bowlers	**11**	6	4	5	4.47
Top 20 in last 10 years; spent 1 > month in top 20	All Disciplines	**50**	37	30	40	5.26
	Batsmen	**22**	20	19	19	0.30
	Bowlers	**28**	17	11	21	7.89*
	Pace Bowlers	17	12	6	**18**	6.85
n = 157	Spin Bowlers	**11**	5	5	3	6.01
Top 20 in last 10 years; spent 3 > years in top 20	All Disciplines	**41**	29	26	25	5.38
	Batsmen	**17**	13	15	10	3.39
	Bowlers	**24**	16	11	15	5.40
	Pace Bowlers	**17**	11	6	13	5.34
n = 121	Spin Bowlers	**7**	5	5	2	2.68
Top 10 in last 20 years	All Disciplines	**50**	32	32	33	4.86
	Batsmen	**23**	20	21	11	4.16
	Bowlers	**27**	12	11	22	10.11*
	Pace Bowlers	**19**	7	7	18	10.40*
n = 147	Spin Bowlers	**8**	5	4	4	2.05
Top 10 in last 10 years; spent 1> month in top 10	All Disciplines	**39**	27	19	25	6.22
	Batsmen	**17**	15	13	8	4.56
	Bowlers	**22**	12	6	17	9.45*
	Pace Bowlers	13	9	3	**14**	9.83*
n = 110	Spin Bowlers	**9**	4	3	3	5.64

Note: **Bold** numbers indicates overrepresentation among birth quarters

* < .05 ** <.01

Study 2

Table. Quarter distribution frequencies of rugby union players across super-elite criteria and positions aligned with individual competitive season cut-offs

Criterion of Super- Elite	Positions	Q1	Q2	Q3	Q4	χ^2
Minimum 20 caps; Last 20 years *n* = 691	All Positions Backs Forwards	152 75 77	**184** **78** 106	173 75 98	182 74 **108**	3.72 0.11 6.21
Minimum 20 caps; Last 20 years; 50% > Team Success *n* = 495	All Positions Backs Forwards	108 **55** 53	122 54 68	123 51 72	**142** 51 **91**	4.71 0.25 10.33*
Minimum 20 caps; Last 10 years; *n* = 300	All Positions Backs Forwards	72 **39** 33	68 30 38	75 31 44	**85** 34 **51**	4.50 1.47 4.51
Minimum 20 caps; Last 10 years; 50% > Team Success *n* = 198	All Positions Backs Forwards	47 **24** 23	47 20 27	49 17 32	**55** 22 **33**	0.88 1.30 2.26
Minimum 30 caps; Last 20 years; *n* = 489	All Positions Backs Forwards	115 **59** 56	**134** 58 76	112 51 61	128 47 **81**	2.69 1.84 6.20
Minimum 30 caps; Last 20 years; 50% > Team Success *n* = 354	All Positions Backs Forwards	78 38 40	**93** 38 55	90 **41** 49	**93** 34 **59**	1.74 0.65 4.04
Minimum 30 caps; Last 10 years *n* = 207	All Positions Backs Forwards	57 **28** 19	49 21 28	43 15 28	**58** 22 **36**	2.43 3.96 5.21

Minimum 30 caps; Last 10 years; 50% > Team Success *n* = 131	All Positions Backs Forwards	**36** **20** 16	32 12 20	29 9 20	35 14 **21**	0.63 4.70 1.15
Minimum 40 caps; Last 20 years *n* = 352	All Positions Backs Forwards	**96** **41** 55	92 33 **59**	83 33 50	81 27 54	1.76 3.95 0.74
Minimum 40 caps; Last 20 years; 50% > Team Success *n* = 255	All Positions Backs Forwards	60 **28** 32	63 26 37	60 21 39	**72** 24 **48**	3.52 1.08 3.44
Minimum 40 caps; Last 10 years *n* = 135	All Positions Backs Forwards	35 **20** 15	34 19 15	27 7 20	**39** 14 **25**	2.22 7.08 3.66
Minimum 40 caps; Last 10 years; 50% > Team Success *n* = 87	All Positions Backs Forwards	24 **13** 11	18 6 12	19 5 14	**26** 11 **15**	2.06 5.11 0.78
Minimum 50 caps; Last 20 years *n* = 248	All Positions Backs Forwards	56 **31** 25	56 21 35	**71** 22 **49**	65 25 40	2.62 2.46 8.08*
Minimum 60 caps; Last 20 years *n* = 172	All Positions Backs Forwards	27 16 11	47 16 31	**65** **25** **40**	33 12 21	19.91** 5.26 18.24**

Notes: **Bold** numbers indicates overrepresentation among birth quarters

***** < .05 ****** <.01

Supplementary Information: Chapter 3

The Identification of 'game changers' in England Cricket's developmental pathway for elite spin bowling: A machine learning approach.

The aim of this supplementary document is to present:

1) Detailed evidence that underpins the findings offered in the main paper, divided into quantitative and qualitative sections.

2) The quantitative interview schedule

1) Underpinning Evidence

Quantitative Section

Supplementary Table. The 93 features of development initially entered into quantitative analysis (numbered)

Feature Number	Feature Labels
1	Birth Quarter
2	Place of Birth Size
3	# of Siblings
4	# of Older Siblings
5	Age Left Family Home
6	Was Primary School your Principle Place for Sport Practice?
7	Was Primary School a Designated Sport School?
8	Went to a Grammar school?
9	Went to Higher Education?
10	Age Left Education
11	# of Organised Sports Played
12	Age Started Organised Cricket Practice
13	# of Organised Practice Hours up to Age 14
14	Intensity of Organised Practice up to Age 14
15	# of Organised Practice Hours up to Age 17
16	Intensity of Organised Practice up to Age 17
17	# of Organised Practice Hours up to Age 20
18	Intensity of Organised Practice up to Age 20
19	# of Organised Practice Hours Before Age of Senior International Debut
20	Intensity of Organised Practice Hours Before Age of Senior International Debut
21	# of Organised Practice Hours up to First XI County Cricket Debut
22	Intensity of Organised Practice Hours up to First XI County Cricket Debut
23	Age of First Organised Cricket Competition
24	Age of First Organised Spin Specific Practice
25	Proportion of Spin Specific Practice up to Age 14
26	Proportion of Spin Specific Practice up to Age 17
27	Proportion of Spin Specific Practice up to Age 20
28	Proportion of Spin Specific Practice up to First XI County Cricket Debut
29	Age Started Bowling Spin Bowling Overs in Competition
30	Mean of overs bowled up to First XI County Cricket debut
31	# of Cricket Competition Hours up to Age 14
32	Cricket Competition Intensity Hours up to Age 14
33	# of Cricket Competition Hours up to Age 17
34	Cricket Competition Intensity Hours up to Age 17
35	# of Cricket Competition Hours up to Age 20
36	Cricket Competition Intensity Hours up to Age 20
37	# of Cricket Competition Hours up to Age of Senior International Debut
38	Cricket Competition Intensity up to Age of Senior International Debut
39	# of Cricket Competition Hours up to First XI County Cricket Debut
40	Cricket Competition Intensity up to First XI County Cricket Debut
41	Age of First Regular Involvement in Cricket
42	Age of First Involvement Playing Family/Friends
43	Age of First Involvement in Unsupervised Practice
44	Age First Played Organised Cricket vs. Older Kids
45	Age First Thought About Becoming a Professional Cricketer

46	Age of First Regular Training with a Cricket Team
47	Age of First Regular General Fitness Training
48	Age Decision Made to Become Professional Cricketer
49	Age of Specialisation in Cricket
50	Age of Specialisation in First Discipline
51	Age of First Off-Season Cricket Training Camp
52	Relocated to Attend Regular Cricket Training?
53	Age when First had Close Relationship with a Coach
54	Age First Joined a County Cricket Academy
55	Age First Selected for an ECB Training Squad
56	Highest Level of Cricket Competition Representation by Age 14
57	Highest Level of Cricket Competition Representation by Age 17
58	Highest Level of Cricket Competition Representation by Age 20
59	Age of Senior Club Cricket Debut
60	Physical Size when First Played Senior Club Cricket
61	Level of Challenge Encountered when First Played Senior Club Cricket
62	Years Taken to Achieve a First Significant Performance in Senior Club Cricket
63	Years Taken to become the Best Spin Bowler in Senior Club Cricket Team
64	Age of Second XI County Cricket Debut
65	Physical Size when First Played Second XI County Cricket
66	Level of Challenge Encountered when First Played Second XI County Cricket
67	Years Taken to Achieve a First Significant Performance in Second XI County Cricket
68	Years Taken to Become the Best Spin Bowler in Second XI County Cricket Team
69	Age of First XI County Cricket Debut
70	Physical Size when First Played First XI County Cricket
71	Level of Challenge Encountered when First Played First XI County Cricket
72	Years Taken to Achieve a First Significant Performance in First XI County Cricket
73	Years Taken to Become the Best Spinner in First XI County Cricket Team
74	Age Became a Regular First XI County Cricketer
75	Age Became Regularly Involved in Any Unstructured Sport
76	# of Cricket Play Hours up to Age 14
77	Cricket Play Intensity up to Age 14
78	# of Cricket Play Hours up to Age 17
79	Cricket Play Intensity up to age 17
80	# of Cricket Play Hours up to Age 20
81	Cricket Play Intensity up to Age 20
82	# of Cricket Play Hours up to First XI County Cricket Debut
83	Cricket Play Intensity Hours up to First XI County Cricket Debut
84	# of Unsupervised Cricket Practice Hours up to Age 14
85	Unsupervised Cricket Practice Intensity up to Age 14
86	# of Unsupervised Cricket Practice Hours up to Age 17
87	Unsupervised Cricket Practice Intensity up to Age 17
88	# of Unsupervised Cricket Practice Hours up to Age 20
89	Unsupervised Cricket Practice Intensity up to Age 20
90	# of Unsupervised Cricket Practice Total Hours up to First XI County Cricket Debut
91	Unsupervised Cricket Practice Intensity Hours up to First XI County Cricket Debut
92	# of Unsupervised Cricket Practice Hours up to Age of Senior International Debut
93	Unsupervised Cricket Practice Intensity up to Age of Senior International Debut

Qualitative Section

Supplementary Details of the Qualitative Data.

This qualitative report identified commonalities and differences between England- and County-level spin bowlers that emerged from responses to questions asked during interviews. The qualitative interview data was obtained from the interview session that were conducted to obtain the quantitative data (described in the manuscript 'method' section). The qualitative interview guide was divided into four questions: Question 1 aimed to establish what challenges professional players had to face along their pathway and how they managed to overcome them; Question 2 tried to establish the single biggest influence on the professional spin bowlers' development; Question 3 aimed to establish if there were any significant learning experiences or key moments during the development of the players' careers. Question 4 concluded by giving participants an opportunity to add additional information that would be helpful to understand the spin bowler's journey.

1.0 Question 1a: What were the biggest challenges you had to face along your pathway as a spin bowler?

1.1 Commonalities:

1.1.1 *The challenge of being selected for teams and avoiding being dropped.* Answers to this question highlight the biggest challenges senior spin bowlers had to face their pathway as a spin bowler. Analysis revealed that 5 England players and 5 County-level players contributed similar quotes to the node; highlighting that the biggest challenges both England and County-level spin bowlers had to face during their development were getting selected for the team, and avoiding being dropped from the team. Since these quotes were equally and substantially represented across both England and County players we consider this theme to be a commonality across the two groups.

1.1.1.1 *Quotes from England-level spin bowlers:* The quotes below come from 5 England spin bowlers highlighting '*selection*' and '*avoid from being dropped*' as the biggest challenges the players had to face along their pathway.

The biggest challenge for 3 England players was to get selected for the team:

> P 16: "I suppose the biggest challenge was trying to get picked to play, but then I overcame it by working hard, practising hard. Same with the spin really, get selected, then just work harder and harder. So generally, I just worked harder. The biggest obstacles I suppose were then getting used to getting dropped".
>
> P. 20: "The biggest challenges for me were getting a regular place in the team. Part of that was driven by the changing nature of the game in terms of seam bowling become more prevalent in the game, shall we say?... There's that element to it there, and also just the challenge of trying to get yourself into the position of number one spin bowler at the club so that you played all the games".
>
> P 7: "I think, not getting selected, just created the hunger more for me. Like, failing".

The biggest challenge for 2 England players was to avoid from being dropped from the team:

P19: “Biggest challenges? I found bowling spin easy. It came easy to me when it happened. I didn’t find it difficult. I think the hard times were playing, as I was evolving as a cricketer, and going up and playing each level, the cricket got tougher. They were the challenges. In developing to survive and perform at every level that you play, and getting there. Sometimes you would get there and all of a sudden your progress would stop, and you needed to play at that level for a while before you actually started to move up again”.

P 21: “The biggest challenges were, being over-coached, lack of form, and getting dropped”.

1.1.2 *Quotes from County-level spin bowlers:* Similar to the England players, 5 County-level players indicated that getting selected, and being dropped from the team were some of the biggest challenges they had to face during their development.

Three County-level players mentioned that it was difficult to get selected, as there were many good spin bowlers competing against one another for a place on the team:

P 29: “What were my biggest challenges? Dealing with not getting selected. I said earlier about being the second spinner often, so being not selected would happen quite a few times, even when you thought you should be. You know yourself that you were bowling really well, but in that period, the wickets might not be quite right and you get left out. You’d miss out on playing for a bit, and you’d lose your bit of form”.

P 25: “The biggest challenge for me back then was that there was so many of us. There were quite a few spin bowlers. It wasn’t the fact that I didn’t believe in myself. There were a lot of us and fighting for places back then was tough. It was a big mental challenge to get through it”.

P 23: “Then go on to professional staff and we had too many spinners on the staff, really. We shared development, is how I viewed it, looking back. That would be the biggest challenge”.

One County-level player recalled that it was difficult to get selected for the team, since he was not a good all-rounder cricketer:

P 30: “The biggest challenges – I was a specialist. I didn’t bat and I was a really average fielder, so I was either bowling well or I wasn’t in the team. So that was the challenge, that sense of being a bit of an artiste, you know, a luxury player; you’re known as the second spinner a lot. So that was that. So not being a good enough all-round athlete and not offering anything with the bat”.

Whereas, 1 County-level player mentioned that as soon as he showed signs that he was feeling weak or struggling he would be dropped from the team. Subsequently, he ended up pretending that everything was fine in order to keep his position in the team.

P 24: "I was struggling with bowling, like a senior coach, or a coach or a player. Sometimes you feel weak or something and you would get dropped. Sometimes, you are better off just to say nothing, and not get dropped. Try and bluff your way through it, as it were".

1.2 Additional answers – England-level spin bowlers:

The following quotes are additional answers to the question relating to the biggest challenges professional players had to face along their pathway as a spin bowler. Six England players identified challenges along their pathway as being: not having necessary guidance and support; playing against older men from an early age; wanting to play cricket in a rugby dominant area; and getting oneself into the number one spin bowler position.

1.2.1 *Insufficient guidance and support.* The biggest challenge for 2 England players was not to have sufficient guidance and support when they needed it the most.

1.2.1.1 *Quotes from England-level spin bowlers*: P 17: "The biggest challenges were when things were going wrong, and you needed help, and often there was no help available. You'd got to bowl and bowl and bowl until you felt it was going better, and often that was not a good thing because you can bowl and bowl and eventually you get tired and bad habits start developing. So that was a hard part, getting somebody who knew enough about spin bowling to help you through a situation when the balls aren't coming out right, it's not spinning or it's not… You were basically on your own for too many moments".

P 16: "I suppose the obstacles were not knowing my game, because I just did it, and nobody taught me how to understand my game".

1.2.2 *Playing against older men from an early age.* Two England players perceived playing cricket against older men from an early age as one of their biggest challenges along their pathway:

1.2.2.1 *Quotes from England-level spin bowlers*: P 21: "Being put in men's cricket at young age and getting slogged around. Playing on small grounds in league cricket. You've just got to become more resilient, you've got to bat yourself, you've got to practice more. Playing first-class cricket, playing on very good wickets against better players and learning to adapt to conditions and things like that".

P 18: "Playing against men at an early age, and good seriously good players that. Like I say, 30+, played a lot of cricket. Yes, so overcoming that through doing it".

1.2.3 *Playing cricket in a rugby-dominant area*. One England player recalled that the biggest challenge for him was to say that he wanted to play cricket. This was especially challenging, as the player grew up in an area where rugby was a more dominant sport.

1.2.3.1 *Quotes from England-level spin bowlers*: P 22: "As in choosing cricket ahead of rugby? That was it, yes. As in, sort of, saying to where I lived that I wanted to play cricket, not rugby. That was it, yes. Not to say that I would have been a proper rugby player but everybody where I lived expects you to play rugby and why play cricket?

1.2.4 ***Working towards the number one spin bowler position.*** A particular challenge for 1 of the England players was to get himself in the number one spin bowler position, as he not only wanted to play at all the matches, but he also had the desire to improve as a bowler.

1.2.4.1 ***Quotes from England-level spin bowlers*****:** P 20: “There’s that element and also just the challenge of trying to get yourself into the position of number one spin bowler at the club so that you played all the games. As a consequence of that, you got the bowling opportunities and the overs to justify your existence and get better”.

1.3 Additional answers – County-level spin bowlers:

Four County-level players identified challenges along their pathway as being: logistical problems; limited access to facilities; not having the necessary guidance; and playing against world-class players.

1.3.1 ***Logistics and financial constraints.*** Logistics and financial constraints were identified as being two of the biggest challenges by 1 County-level player.

1.3.1.1 ***Quotes from County-level spin bowlers*****:** P 28: “My biggest challenges were obviously the area that I lived, and logistics. Logistics would have been a huge obstacle for me, finance would have been a huge obstacle. My father ended up being a taxi driver. I used to have to travel by bus and an over-ground train at a young age to try and play cricket, with not a lot of money. The environment I lived in. Not many people played cricket. Therefore, there weren’t that many connections. What other obstacles were there potentially? I’d have said they’d have been my biggest players”.

1.3.2 ***Limited access to training facilities and lack of guidance.*** Limited access to training facilities to practice, and not having guidance on what it takes to become a professional cricketer, were some of the biggest challenges 1 County player endured.

1.3.2.1 ***Quotes from County-level spin bowlers*****:** P 26: “I think the biggest challenge was having to know what it took to become a professional cricketer. The structure I went through, it wasn’t like a private school where you had all the facilities. My structure was more state school, get on with it sort of thing. If I’d known earlier what it took, if I’d had the facilities to practice what I wanted to back then, I reckon it might have started sooner. The biggest challenge was, basically, facilities and trying to get access to them”.

1.3.3 ***Challenges of bowling in competition.*** Playing against world-class cricketers proved to be very taxing for 2 County-level players. For 1 County player in particular, it was overcoming the mental aspect of playing against some of the best players in the world.

Whereas, 1 County-level player recalled that it was challenging for him to bowl as the second spinner in the team, especially in instances where the batsmen had already established a firm base:

1.3.3.1 ***Quotes from County-level spin bowlers*****:** P 25: “I think it’s getting over who you’re bowling against. Like you say, you hear about people and the names that are in world cricket and then next week you are playing against them. You’re there, you might be batting or bowling against Brian Lara. You’ve got to overcome that mental aspect of, “He’s one of the best players in the world,” or, “He’s the quickest bowler in the world.” You’ve got to switch on and say, “It’s good. If I can get him out then that makes me a half-decent bowler.” It’s that challenge, it’s that thing of, “I want the ball, I want to get him out.” That was the challenges that you face, that every week you are two or three world class bowlers in every side and you had world class batters in every side. Now you don’t get it so much because overseas pros don’t come over so much or you might have one. Whereas back then you had two bowlers or two or three batters that were quality. Yes, it was a good challenge but it was nice to overcome them and do well at it at times”.

P 29: “Well, playing against good players, that was always a challenge, as well as captains not bowling you in times when the odds were always stacked against you. Often, spinners would come on, happened a lot, especially as being massively the second spinner. By the time I came on, batters often were set, ready to go, yes, might have 80 or 90 to their name, or you would bowl at the end, that wasn’t as good a place to bowl spin as another end, because you were the second spinner”.

2.0 Question 1b: How did you overcome these challenges?

2.1 Discriminators:

2.1.1 ***Overcoming challenges through hard work and practice.*** The answers to this question describe how some professional spin bowlers managed to successfully overcome challenges, and how other professional spin bowlers failed to overcome those challenges. Thematic analyses of the quotes revealed three sub-themes, namely, overcoming challenges by seeking and listening to advice, overcoming challenges through hard work and practice, and difficulties in overcoming challenges.

This sub-theme reflects professional spin bowlers’ ability to overcome challenges through hard work, practice, and by bowling on various pitches. Analyses revealed that 7 England players and 3 County-level players contributed comparable quotes to this sub-theme. Since the quotes provided were almost double the proportion of England players relative to County players, we interpreted these results as a differentiator. Suggesting, England spin bowlers were more likely than County-level spin bowlers to have overcome the development challenges they faced by engaging in hard work and practice.

2.1.1.1 ***Quotes from England-level spin bowlers:*** Seven England-level spin bowlers recalled that they managed to overcome challenges through practice, hard work, and by bowling on various pitches:

P 16: “I suppose the biggest challenge was trying to get picked to play, but then I overcame it by working hard, practising hard. Same with the spin really, get selected, then just work harder and harder. So generally, I just worked harder”.

P 20: “Okay, you’d overcome them by working hard and practising in the net to try and make yourself better. You’d overcome them by trying to bowl as best you could in Second Team cricket, so you’d try and force your way into the side. Also try and bowl as best you could in First Team cricket as well so that you kept your place in the side”.

P 22: “I got hammered by one batsman and then my father had a chat about line and pace. I bowled too slow and I bowled too straight. We practiced for hours and hours and I managed to take what I’d practiced into the game. I got the lad out early on, bowled the way that I practiced and it was successful, so the penny dropped. Success from the practice”.

P 6: “Bowling and bowling, and getting to know about bowling. Getting to know about your body”.

P 17: “You’ve got to be stronger now than I think you used to. Not strong as in you can run fast, you’ve got to be strong in the shoulders so you can bowl for long period if necessary. But how are you going to do that if you don’t practice bowling. If you don’t practice bowling on pairs you can’t suddenly bowl 40 overs in a day because you’ve never done it”.

P 21: “Using different sized balls when you’re practising, using little win balls when you’re a young kid. Trying to hold it differently. What else? Just being patient with thinking that you’re going to grow, so you just had to be patient”.

P 19: “It takes time to develop, A, your skills in terms of control. Learning to bowl on the various pitches that you’ve played on. The consistency, flight, pace, length, line. All the basics. It’s not until you nail those down and become consistent, and you are confident that you can bowl that ball into the area that you can”.

2.1.1.2 *Quotes from County-level spin bowlers*. Similar to the England players, 3 County-level players indicated that they managed to overcome challenges through hard work.

P 29: “I’d say the way I dealt with that most of the time, well, sometimes was to get grumpy, irritable, pissed off and blame other people. I guess when I wasn’t doing that, just work harder to get better, very simply”.

P 26: “You’ve got a bat and ball and you’ve got a wicket laid out, so get a grip. Get a few mates and just practice.” Quantity rather than quality. That was the best of the situation I had to make out of it, rather than having a really good indoor school that I could ring up and go and get coached. I just had to make the best out of what I could. At a young age I realised that putting in hours would be the best thing for me to get better”.

P 25: Just to be confident in what you do and just have that mentality of, “Right, I’m going to spin the ball and I’m going to be really focused on what I do.” Practice well, train well.

2.1.2 *Difficulties in overcoming challenges.* One sub-theme that was unique amongst County-level players was experiencing difficulties in overcoming development challenges. Some of the difficulties forwarded by County-level players to successfully overcome development challenges include but are not limited to: nervousness about performance, fear of failure, not equipped to cope with high-level expectations, and lack of support/help.

2.1.2.1 ***Quotes from County-level spin bowlers****:* The following quotes are from 6 County-level spin bowlers indicating difficulties they experienced in overcoming challenges.

One County-level player mentioned that he was not equipped to cope with high-level expectations and pressure:

> P 27: "Then you start to learn the game and you realise that as a spin bowler you need to be pretty accurate, you need to be only going a three runs and over maximum let's say in the first innings and then get your wickets in the second innings. With that understanding there comes expectation and pressure you put on yourself and again that causes crunch points. I wasn't equipped to deal with those crunch points".

Another County-level player admitted that he did not manage to overcome challenges, as he was nervous about his performance, and had a fear of failure:

> P 23: "I'm not sure I ever really did [overcome those challenges]. Looking back, there is part of me that loved the challenge of playing and loved the moment. There is also lots of nervousness about performance and fear of failure. I was always trying to find something else to get better. I did, in some ways, because I was like, "Right, I'm going to find my own path and go away and pursue it." Equally, I need some people to help me, you know, looking back".

One County-bowler acknowledged that he was unable to successfully overcome his challenges even though he was a good bowler, and had some good performances. However, there were other bowlers who were just as good as him with the ball, but who had more to offer with regards to batting and fielding:

> P 30: "No, I never really overcame these challenges. I mean, I was a pretty good bowler and had some good performances, but I didn't do like [X] did: he would get 80 wickets at county season and things like that – that was the era then, and you know, I was a 50 wickets a season spin bowler, when we played more and things like that, in a field of people that did better than me. Did better than me, generally, or offered a bit more with the bat as well as being as good as me with the ball and things like that. I was pretty good, I was a pretty good county cricketer, but I was no better than that, really".

One County-player was of opinion that if he had received the necessary guidance / help earlier on during his development, he would have started sooner in First-Class cricket:

> P 26: "I think the biggest one was having to know what it took to become a professional cricketer as, you see, the structure I went through, it wasn't private school and you had the facilities and all that. My structure was more state school, get on with it sort of thing. If I'd known earlier what it took, if I'd had the facilities to practice what I wanted to back then,

I'm not sure because I've made it into first-class cricket now, but I reckon it might have started sooner".

It was also argued by 1 County-player that if one practices without the necessary guidance, one is not necessarily going to improve:

P 27: "Yes, so my philosophy was the more balls I bowled, the better I would become. I think it's a decent attitude to have but it needs guidance because if you're not practising the right things, you're not necessarily going to become any better. I think that was the case with me, I had a massive desire to be better. I was always one of the fittest cricketers on the staff, I always bowled the most balls but the unstructured practice I think was significant".

One spin bowler thought that he would have progressed quicker if he had had more help:

P 24: "I didn't really progress as quick as I probably could have done, if I'd have had a bit more help like they do nowadays".

2.2 Commonalities:

2.2.1 ***Overcoming challenges by seeking and listening to relevant advice*****.** This sub-theme reflects professional spin bowlers' recollection on how they managed to successfully overcome challenges by seeking advice or feedback from experienced bowlers and coaches. However, the spin bowlers would filter out any unnecessary information, only to take away information that has relevance to them. Analyses revealed that 6 England-level spin bowlers and 4 County-level spin bowlers contributed quotes to the sub-theme. Since the proportions of England and County-level players who contributed quotes to the sub-theme are broadly similar, this sub-theme was considered to be a commonality across the two groups of players.

2.2.1.1 ***Quotes from England-level spin bowlers:*** The following quotes come from 6 England-level spin bowlers, recalling how they managed to overcame challenges by seeking out and listening to advice; thereafter, they would only select and use relevant information that they felt would be pertinent to them:

P 17: "Finally, the member of the team who knew a bit about the game, you'd talk to them a lot. I would talk to [X]. He would say, "You might be going a bit slow, you're bowling a bit quickly. You're not putting enough energy into it". So I'd be learning on my own a bit, asking questions and just searching".

P 22: "Trying to get as much feedback as possible from other people. Try and pick good sources. Work with wicket keepers but generally from the coach".

P 21: "[X] who I've said was my mentor from a young age, I would phone him up, getting back to doing the basics. Using a sports psychologist. Yes, little things like that I suppose".

P 2: "If I was asked the question from a young fellow now, who was 16, I would say, you have to be your own Coach, you have to work things out for yourself. Use the eyes and ears, and knowledge of a Coach, but ultimately, you've got to know what direction you're going in. Because I just believe Coaches that are talking to spinners will always have information, that most of it, its relevance to that individual is minimal".

P 3: "I ignored the Coaches basically, all along, and I didn't hold the ball as they suggest you should. Because I found that it didn't work very well. That was from the age of about eight onwards. So I ignored conventional wisdom, when it came to off spin bowling. I thought off spin could offer a hell of a lot more than was accepted as the sort of output that spinners should give in England".

P 4: "It's the same for the coaching, is that, I think early on when you're young, you listen to too many voices. Without filtering it out and working out, and as you get older you pay lip service for things and you say, "Thanks very much," because everyone means well".

2.2.1.2 ***Quotes from County-level spin bowlers:*** The following quotes were taken from 4 County-level spin bowlers recalling how they managed to overcome challenges. Similar to the England players, County-level players would listen to advice from coaches, then filter out any unnecessary information, and only retain that what has relevance to them:

P 27: It's still knowing who to trust as coaches and what information to take on board but always to be accountable. Also, trust as well. Which coaches you could trust. Everyone would have an opinion and it was trying to make sense of what was right and what was wrong. You'd try all sorts of things but essentially, I was scrambling trying to find a method to make me a better bowler".

P 24: "It's just you got to have to belief in yourself. Yes, you've got to have a plan and an end goal to reach for. Don't try and please everyone. When one coach says, "Oh, this is the way we do it", don't try and please him if you don't believe him. I know it's easier said than done. Take everybody's advice, or look like you're listening to people. I might talk sh*t for half an hour, but then I might say one sentence and you think, "I will use that". Bring that into your game and don't be shy about getting advice. Not taking it, but maybe just use snippets".

P 25: "I had the mentality of not switching off but filtering what people said to me. You can quite easily go down the road of pleasing everybody. I'm not saying, "What I say is right all the time," but I'm saying, "Try what I say. I've got no problems if it doesn't work for you but try it. If it does, brilliant; if it doesn't, then move onto the next thing. Don't try and take in too much all the time. Just have the confidence to try and do what you do and that's spin the ball".

P 29: "Be good at working out what works for you, and what's right for you. That is massively an important underrated skill for any cricketer, especially a spinner, because you'll get some rubbish advice. Take on advice, but be good at sifting out what's good and what will work for you. Always believe in what your strengths are what makes you work well, bowl well, and don't err from that".

2.3 Additional answers – England-level spin bowlers:

The following quotes are additional answers to the question relating to how professional players managed to overcome the challenges along their pathway as spin bowlers.

2.3.1 ***Moving Counties to gain more bowling experience.*** One England player recalled having to move twice to different Counties to gain more bowling experience because his progress within team was hindered by better bowlers within the team,

> **2.3.1.1** ***Quotes from England-level spin bowlers:*** P 20. "I also changed counties twice. At XXXXX where I started my career, my pathway was blocked by [X] who was a really fine off spin bowler. He played for England and he was a real quality bowler, so I learned a lot from him. It was great to play with him but I got to a stage where I wasn't playing anywhere near as much cricket as I felt to ought to or would like to do so I moved county. I moved and played pretty much a full season, particularly in the Championship cricket and went pretty well. Then we got into the era of high seamed balls and green pitches and I was marginalised. After three years I then moved to another County, where things progressively got better as the pitches were a little bit more favourable with spin bowling, so you got more of an opportunity there".

2.4 Additional answers – County-level spin bowlers:

2.4.1 ***Lifestyle changes.*** One County-level player had to make certain life-style sacrifices, as well as train harder to overcome the challenges of being a professional cricketer.

> **2.4.1.1** ***Quotes from County-level spin bowlers:*** P 24. "A thing to overcome was trying to get used to being a professional, is a different kettle of fish. Saying no to my mates, not going out nightclubbing, boozing every night or doing whatever they did. As a young kid, growing up, you make sacrifices. Training a lot, going to different camps, driving here there and everywhere".

3.0 Question 2: What had the single biggest influence on your development as a spin bowler?

3.1 Commonalities:

3.1.1 ***The influence of significant others on spin bowling development.*** Answers to this question reflect England and County-level players' perception of the single biggest influence on their development as a spin bowler. Analysis of the interviews indicated that significant others (i.e., family, captains, and coaches) had a considerable influence on the spin bowlers' development. In total, 8 England players and 6 County-level players contributed comparable quotes to the theme. In light of the substantial proportion of both groups of spin bowlers who identified similar influences, we considered this theme to reflect a considerable similarity between the two groups.

3.1.1.1 ***Quotes from England-level spin bowlers*:** The following quotes come from 8 England-level players identifying captains, coaches, and family members as being the biggest influence during their development as a spin bowler.

Five England players identified team captains or coaches to have had a considerable influence on them during their development:

> P 19: “Captaincy, without a doubt. Having a good Captain who understands spin, allows you to develop as a spin bowler, not rushing you, giving you the overs. I think the structure that we probably play now is certainly a lot tougher for young spin bowlers to come into, and through, because of the type of cricket played and divisional cricket”.

> P 17: “Well the biggest influence was the guy next door to me, my coach. He was the one. Then the ability to talk to all the great spin bowlers in the country. [X] was probably the best. So when we played him, I would say to him in the bar, “What did you think today, [X]?” And he might say, “Yes, you looked good today. You might push it through a bit more, or you might do-” They would be watching me bowl and all the opposition spinners, they’d watch you and then sometimes they’d give you help and that. That doesn’t happen anymore”.

> P 21: “[X] I reckon. Yes, and actually getting someone who bowled spin and who played for England. Listening to him and him taking a huge effort into putting some work into me”.

> P 16: “I suppose being encouraged. Like I said, I didn’t receive encouragement specifically, but I was encouraged a lot by a couple of old spinners. A guy called [X] at the club, a cricketer who played for England, and also a guy called [X], ex-England. They were my coaches so they encouraged me”.

> P 1: “I think the strong influences are important, so the family influence. I was almost immersed in a cricket environment from very early on, but there was far more than that, so a lot of unstructured play, just catching, hitting, bowling, and at that early age, a very, very good coach, who was a hard taskmaster but very knowledgeable”.

Three England players identified family members who had knowledge or played cricket themselves (e.g., father, brother) to have had a considerable influence during the players’ development as a spin bowler:

> P 18: “He [my father] was a slow bowler as well. Although, once you get into your teams you don’t talk so much to your father. Being able to genuinely talk cricket and spin bowling to him, daily, sometimes without even knowing it, you know? It was pretty important. I think that nurturing thing, of having senior people, trusted senior people who were around that would give a young guy opportunity, is huge. We used to play a lot of time cricket, you know, those midweek games when I used to go out of school, nip there, get there at 3 o’clock or whatever”.

> P 22: “It was probably my father. He was the first one who told me a good line to bowl and emphasised the importance of bowling a good pace, so that was that”.

> P 8: “I think family background is quite, we kind of briefly maybe mentioned it, but I think having an older brother who I did a lot of training with and talking about cricket, was, yes,

was pretty essential, I can say that. And the other thing is having parents who are, have the capacity to travel and to drive and time to take you to places; that is huge".

2.1.3.1 ***Quotes from County-level spin bowlers:*** Similar to England-level players, 6 County-level players also identified captains, coaches and family members to have had the biggest influence on their development as a spin bowler.

Four County-level players identified their coaches or captains to have had a considerable influence on them during their development:

P 30: "The captain at the club when I was a kid, you know, playing cricket, he thought I was a good player and had thought I could play for a living, like, genuinely thought it. You know, you can see it in somebody's eyes. And then winning the sort of trust of [X] here as Captain, [X] as a captain ... And then, later on [X[who was a sensational coach, again, for a period of time really, really helped me no end and helped me make sense of what bowling is and things like that, "This is what you have to do." I'd say that was it, really".

P 28: "I'd probably say invited to Lord's and practising under the guidance of [X]".

P 29: "Well, the moment when [X] said to me, "You're going to be too little, you're never going to be able to bowl quick. What are you doing bowling seamers? You're a little midget. You need to bowl spin. I think you can bowl spin, probably." Making that move at 14 to start bowling spin, probably that's the biggest thing. Yes, that's the biggest thing".

P 26: I think the massive one was one we discussed earlier. When I was 21 I had to make a choice whether to drop cricket or carry on, but then drop the workforce or the work environment. I didn't want to really make that decision that quickly, so I was fortunate I'd got Uni to fall back onto. That still allowed me 2 years where I could still choose doing both and then it was just a toss of the coin when [X] called me up saying, "Look, we want you to train with us." From there it just really kicked off, so I guess that was one of the biggest stages of my career".

Two County-level players felt that their fathers were the biggest influence during their development as a spin bowler:

P 25: "Been the single biggest influence? Probably my dad, telling me at 11, quite brutally, as much as I didn't like it at the minute at that point, telling me, "I think you are better bowling in spin." Probably changed me from a medium paced spin bowler at 10, 11, to a spin bowler and saying, "You might have a career in cricket, you might not." It probably made me play for 20 odd years, that I have done as a cricketer and not done something else".

P 24: "It was sort of my dad saying at 11, "Do spin bowling".

2.1 Additional answers – England-level spin bowlers:

Two England players identified influences on their development as a spin bowler as being: receiving the County cap in recognition for maintaining good performance over a period of time; and being selected for 4-day cricket provided an opportunity to learn new skills and hone basic skills.

2.1.3 ***Receiving recognition for good performances.*** One of the biggest influences for 1 England-level player during his development as a spin bowler, occurred when he was awarded the County cap in recognition for maintaining good performance over a period of time.

The following quotes are additional answers to the question relating to professional cricket players' perception of the biggest influence on their development as a spin bowler:

3.2.1.1 ***Quotes from England-level spin bowlers:*** P 20. "I suppose one of the things that helped me along the way was when I was awarded my County Cap. A County Cap you have to earn by playing regularly and putting in solid performances over a period of time. I was awarded my County Cap and that was a big confidence boost and it gave me the feeling of, Yes, I've got somewhere. I've got a long way to go but I've got somewhere".

3.2.2 ***Opportunity to compete in 4-day (red ball) cricket.*** Not being selected for one-day cricket but for 4-day cricket had a considerable influence on 1 England player, as it provided him with an opportunity not only to hone his basic skills, but to learn new skills as well.

3.2.2.1 ***Quotes from England-level spin bowlers:*** P 21. "That's one of the big things that helped me. I didn't get selected for Yorkshire in one-day cricket, I got selected for Yorkshire in four-day cricket. It gave me the opportunity to learn the skills and hone basic skills such as spinning the ball hard, flight in the ball, setting field and working out tactically how to get a batsman out.

3.3 Additional answers – County-level spin bowlers:

Three County-level players identified influences on their development as being: the first time the player could spin the ball past international players; playing for a club that provided him with the opportunity to develop different styles of bowling; and receiving rewards along one's talent pathway.

3.3.1 ***Bowling against international-standard batsmen.*** For 1 County-level player, one of the biggest influences during his development was when he managed to spin the ball past international players. That experienced encouraged him to become a professional cricketer.

3.3.1.1 ***Quotes from England-level spin bowlers:*** P 27. "It's really hard because I had such an odd career. I think bowling at international players when I first started being around and being able to spin the ball past them that said to me, "Yes I can do this." That was I guess the thing that really got me going".

3.4.1 ***Performance expectations.*** One County-level player recalled that one of the biggest influences on his development as a spin bowler was when he went to play for XXXXX club. There he was able to bowl many overs, and in the process, develop different bowling styles.

> **3.4.1.1** ***Quotes from England-level spin bowlers:*** P 23. "I think, when I went to play for XXXXX. Instead of being the best spinner or one of the best spinners, I was the best bowler there. It was like, "Well, we are paying you a few hundred quid, here is the ball, don't care if it's a green pitch, flat pitch, spinning pitch, you've got to win us the game." I ended up bowling lots of overs. The standard wasn't as good, but some of them were good. Even then, I used to get people out on wickets that were not conducive or assisting you. I developed my bowl. Loads and loads of bowls, and had to develop different styles of bowling".

Being rewarded along his talent pathway had a considerable influence on 1 County-level player as it provided him with a gauge where he is at and what he needs to do to progress to the next stage:

> P 26. "Obviously getting rewards as you go along helps, but for me, massively, the biggest reward was making my debut, going on to winning the T20 finals, going to India and experiencing the championship there. Another reward was obviously getting selected for my reward, consistent performances in country cricket and to represent the PEPP (Potential England Performance Programme). I guess if you're rewarded for your hard work and performances, I guess that's like a stepping stone as you know where you're at and what needs to be put in to go to the next stage".

4.0 Question 3: Was there a significant learning experience / key moment that took place during your development that eventually contributed to the career you had?

4.1 Commonalities:

4.1.1 ***Conversations with fathers or coaches.*** Answers to this question highlight key moments during professional spin bowlers' development that eventually contributed to their careers. It was interesting to note that both England and County-level players recalled conversations with fathers or coaches as being a key moment, and not a specific achievement event. Results revealed that 3 England players and 3 County-level players contributed similar quotes to the theme. Since the two groups were equally represented in contributing to the quotes, but fewer than half the players in each group provided them, we adopted the view that there was some similarity between the two groups.

4.1.1.1 ***Quotes from England-level spin bowlers:*** The following quotes are from 3 England-level players recalling a significant key moment that contributed to their careers.

A key moment for 1 England-level player was when he received advice from his father after a poor bowling performance against a particular batsman during a match:

> P 22: "...[T]he one thing which was sort of an eureka moment was when I played against a team in the summer when I was about 13. I got hammered by one batsman and then my father had a chat about line and pace. I bowled too slow and I bowled too straight. We

practised for hours and hours and I managed to take what I'd practised into the game. I got the lad out early on, bowled the way that I practiced, and it was successful, so the penny dropped".

One England player recalled that the key moment for him was when his teacher/coach encouraged him to bowl spin after observing him bowl a spin ball:

> P 19: "I think that teacher when I was 12 years old, when I made a ball spin and he said, "Do that again." I spun, and he said, "Well that is all you should do. That's how you should bowl. That's what you should bowl." That for me was a key moment".

Whereas, for 1 England player, the key-moment came when a new coach not only provided him with an opportunity to bowl, but the coach also said that he rated the player higher than any of the other bowlers:

> P 21: "A new coach coming into the club probably kicked off my career. If we would have had the same coach, I don't think I would have got the opportunities that I got when he came. That was a huge confidence boost for me for a new coach to come and say, "No, I rate you more than the other lads even though they're 3, 4 years older than you." That was a huge thing".

2.1.3.1 ***Quotes from County-level spin bowlers*****:** The following quotes are from 3 County-level players recalling a significant key moment that contributed towards their careers.

A key moment for 1 County-level player was when he received advice from his father to listen to lots of people, but only to keep what works for him:

> P 24: "Yes. It was sort of my dad saying at 11, "Do spin bowling." And at 12, 13, I wouldn't say he washed his hands of me, but it was his way of saying, "Right, I have told you everything I can tell you as a coach and as a dad, of how to play cricket." You now need to get, and I would always say this to young kids, you don't just have one person telling you how to bowl, how to back, or how to keep. Listen to hundreds of people, and if they give you a snippet of advice that you enjoy or you think, "Oh yes, that might work." Listen to people, and then take what you feel works for you and your game".

For 1 County-level player, a key moment during his development was when his coach turned him into a left-arm spin bowler:

> P 28: "A key moment? Again, I'd have to pinpoint [coach X] at XXXXX turning me into a left-arm spinner. I think his character probably was something that I could relate to, as well. He had a, I believe, powerful external character that smiled and brought the best out of everyone for encapsulating my wanting to be, or perceiving, that if he can do that and he's only bowling spin as well, then I can portray a similar package".

One spin bowler recalled the time when he had a conversation with both his captain and coach where they informed him that they don't think that he will be able to play first-class cricket at the club. This was a significant experience for him, as it made him more determined to prove them wrong:

> P 25: I think the thing I was talking about before with you was the captain and the coach sitting me down preseason and sort of saying, "We've got a lot of spinners in the side and we don't think you're going to play a first-class game here." I could quite easily have just given up and said, "Okay, I'll look for another club," but I didn't. It gave me the fire in my belly to- "No, I'm going to prove you wrong. Even if I don't prove you wrong, I'm going to go down trying to prove you wrong." That was the key thing for me that turned my focus to toughen me up a little bit it and think, "You've got to have the ball in your hand to get these wickets, so you've got to do it." That was my biggest experience of what it was".

2.1 Additional answers – England-level spin bowlers:

Two England players identified key moments during their development as being: every match was a learning experience regardless of outcomes; and observing and playing alongside other professional spin bowlers:

4.2.1 Learning from competition experiences. For 1 England player, every match was a learning experience, regardless the outcome of the match.

> ***4.2.1.1 Quotes from England-level spin bowlers:*** P 18. "You could go and bowl 10, 12 overs and got smacked around the park. If we lost the game, then so be it. It's still a learning experience".

4.2.2 *Observing and playing with other professional bowlers*. One England player recalled that the key experience during his development involved observing and playing with other professional bowlers. Afterwards, he then tried to imitate the professional players:

> **4.2.2.1 *Quotes from England-level spin bowlers:*** P 17. "Probably watching and bowling with bowlers like Illingworth and Lock. Watching them bowl and working with them, and seeing how they think about spin, or just watching their energy on the crease. Just watching them. Just watching them as great spinners and trying to emulate what they did and their good attributes, and trying to just copy them".

4.3 Additional answers – County-level spin bowlers:

Three County-level players identified key moments during their development as being: having to opportunity to bowl against professional players and see how good they were; bowling on flat pitches for prolonged periods of time; and playing abroad for six months.

4.3.1 *Experiencing the standards of professional cricket.* A key learning experience for 1 County-level player was to bowl to professional cricketers and experience how good they were. That made the County-level player realise that he needed to improve his game if he wanted to play on professional level.

> **4.3.1.1 *Quotes from County-level spin bowlers*:** P 29. "I would say going to bowl to the professionals most Thursday nights, and seeing how good they were and going, "I need to

be a lot better than I am," and then realising there was a massive gulf in how good I needed to be, and then thinking, "Right, come on then. I've got to step up here and get better." That would be that moment, I reckon".

4.3.2 *Bowling on flat pitches for prolonged periods*. One County-level player could not remember a particularly key moment during his development, however, he did mention that bowling on flat pitches for prolonged periods helped to develop him.

4.3.2.1 *Quotes from County-level spin bowlers:* P 23. "I don't think there is any one particular one, but I think bowling on flat pitches. Bowling long periods on that, this built up some development".

4.3.3 *Playing cricket abroad*. One County-level player felt that playing cricket abroad for 6 months was an important learning experience, as it showed real commitment towards one's development.

4.3.3.1 *Quotes from County-level spin bowlers:* P 30. "Playing abroad. To go out for six months is a real commitment in terms of your development. To keep yourself going for that, to manage your own game, to use your own development and things like that, it's really important".

5.0 Question 4: Is there anything else of significance that we have not touched on that would be helpful in understanding your journey to becoming a (county or international) spin bowler?

Answers to this question contain additional information that participants felt would be helpful in understanding their journey in becoming a professional spin bowler. Thematic analysis revealed that no clear comparative or differentiating themes emerged between the two groups. Some of the themes that emerged from the England player quotes include but are not limited to: enjoy the game, knowing what works for you and what doesn't, sense of perspective, multi-disciplined, and support. Some of the themes that emerged from the County-level player quotes include: Right person at the right time (timing), self-belief, and desire to improve. Considering the small numbers of players from either group of spin bowlers contributing quotes to each of these themes, we considered there to be no clear consensus on whether any of the themes was a commonality or a discriminator. In that sense, they might best be regarded as additional answers from the two groups.

5.1 Additional answers – England-level spin bowlers:

5.1.1 *Enjoy the Game*. Two England players stated that players need to remember to enjoy the game. One England-level bowler pointed out that spin bowlers need not only to be crafty, but they also need to play with a smile, so that it looks as if they are enjoying the game. The player went on to explain that when opponents see that the bowler is not enjoying the game, they will try to capitalize on that.

5.1.1.1 *Quotes from England-level spin bowlers*: P 17: "Spinning the ball, being very crafty, and looking as if you're enjoying the game. If you look as if you're as sick as a parrot out there, you...That's why Root is so good, because he plays with a smile on his face, doesn't he"?

P 19: "Apart from enjoying it. I think everyone would say enjoy it, have fun".

5.1.2 ***Understand what works for you and what doesn't***. One England player suggested for players struggling to adjust at England-level, players need to understand what works for them and what not.

5.1.2.1 ***Quotes from England-level spin bowlers:*** P4: "Some people go into the England environment and they struggle with the adjustment, or, with what's being given. Rather than saying, "Okay even at this level, it doesn't mean that's going to work for me." I think the point of that really, is the fact that the sooner you can get the lads to understand that you've got to work it out for yourself, what works and what doesn't, rather than being told. Say, "Right, here's an idea, try it, and if it doesn't work, fine." Rather than saying, "Here's is an idea, you must do it because that's what's going to work." It's not the case".

5.1.3 ***Sense of perspective***. For 1 England player it is important to have a sense of perspective and realism of what is expected in producing a spin bowler. The player is of opinion that they won't be successful in producing a spin bowler is they are going to keep playing T20 or '50-overs' cricket.

5.1.3.1 ***Quotes from England-level spin bowlers:*** P21: "I think a sense of perspective and realism of what we're expecting to produce in England regarding spin bowlers. Graeme Swann was the last successful spin bowler, so why should it change overnight (suddenly), us producing good spin bowlers? Especially in four-day cricket or test cricket when we produce one every 20 years if you like- there has got to be some sense of perspective there and realism about what we're trying to produce. We're not going to produce if we just keep playing T20 cricket or 50 over cricket. It's a completely different kettle of fish playing test cricket and four-day, so it's more what's realistic in what you want to achieve".

5.1.4 ***Multi-disciplined***. One England player highlighted that for a player to be successful, he needs to be multi-disciplined. Meaning that a player should be able to bowl and bat. This would require spin bowlers to become more selfish at times to get a chance to bat.

5.1.4.1 ***Quotes from England-level spin bowlers:*** P 17: "If you're good now, the world's your oyster. You don't get finger spinners now who can play unless they can bat. If you're a leg spinner or a great Muralitharan-type bowler, you can bowl, but the average spinner has got to be able to bat. He's got to be able to bat and get your 50s and get your 70s. Like Swann or these types. You've got to be able to do both now. That's sad, because you've got to make sure the coach lets you have a bat. Sometimes, if you don't push yourself forward, you can easily never bat, if you keep bowling but you don't get a bat. So you've got to be a bit selfish on occasion".

5.1.5 ***Receiving support*.** One England player suggested that players should be supported to help them to develop.

> **5.1.5.1** ***Quotes from England-level spin bowlers:*** P 16: “Support players. Help them evolve, both mentally, physically, but also technically and tactically as well”.

5.2 Additional answers – County-level spin bowlers:

5.2.1 ***Being the right person at the right time*.** Two County-level spin bowlers highlighted that spin bowlers should understand that the team requires different characteristics at different stages in their career. Therefore, it appears important to be ready, at the right place and at the right time.

> **5.2.1.1** ***Quotes from County-level spin bowlers*:** P 28: “Not that we haven’t touched on, but hopefully that it shows that people can come from many backgrounds, many walks of life. I was fortunate to have certain captains to play under, which afforded my character and my style to come to the party. I think it’s important that spin bowl or spinners understand that there are different characteristics required at different stages of their career. It doesn’t help them, but knowing and understanding that puts them in a better position. If you’re a guy, a Nasser Hussain, you want a slightly more defensive-style game because you want to rely on those seamers that you have. As a spin bowler, you have to understand that. The smart ones are the ones that are able to interact and understand what fits into sporting components within that group”.
>
> P 30: “I think we touched on it at the start. I think there’s got to be a space for you in the team. It’s a timing thing as well. You know, I was lucky I came along when the senior left arm slow bowler was at the end of his career. It’s the same with wicket-keepers; it’s the same with spin bowlers: If there’s not a space for you in the team then you don’t get in. So that’s difficult. Yes, I was the right person at the right time. You know, you look at other players I played with and against, they’d come in, they were good players, but there wasn’t a readymade spot for them into the team where they can naturally go in and play. And I was lucky, as well, with the captain that we had; the first captain I had liked me as a person, in terms of, he thought I brought something different to the team, so he liked that. But then other captains, it’d scare the life out of them, you know, that’s the last thing they wanted”.

5.2.2 ***Having self-belief*.** Two County-level players perceived self-belief to be important, as lack thereof would influence performance.

> **5.2.2.1** ***Quotes from County-level spin bowlers:*** P 24: “It’s just you’ve got to have a belief in yourself. Yes, you’ve got to have a plan and an end goal to reach for ... [D]on’t be scared of going for runs as a spin bowler, because that’s how you are going to get wickets. Again, the faster pace, Twenty20 has taken over. I would still like to see spin bowling, and spin bowlers have a stop delivery for red ball. Learn how to get batters out the right way, as it were, back pads”.

> P 23: “Yes, it would be. I had no belief in my ability. No belief in it at all. The ironic thing is, when it got to the game, actually, in terms of some of my performances, got some of the best players in the world out. I could clearly perform. Clearly play. There was a lot of doubt in my ability”.

For 1 County-level player it is about the desire to improve:

> P 26: “I guess for me as a cricketer, I’d always want to improve, regardless of whether it was fitness. Fitness not so much, but I knew I had to improve, so that was one thing. In terms of bowling, I knew where I needed to be. I was looking up to [X] thinking, “Sh*t, this is where I’ve got to be, so what do I need, from A to B? How do I get there? I’d always want to improve my batting. I know I started off at 11. I’ve batted as high as number 6 now for county and averaging 24. It was always about improving”.

5.2.3 ***Receiving recognition***. One County-level player highlighted having received recognition by receiving his County cap had an impact, as he immediately felt more comfortable in his surroundings.

5.2.3.1 ***Quotes from County-level spin bowlers:*** P 10: “I think having the recognition of getting my County Cap, I think that is quite a big part of my development, as far as being accepted and recognised into the First Team. It is like, it is an honour to get your Cap; not many people have got it, you know, this is what it takes to get there. So, I think as far as my development as a County professional, definitely, you know, I felt immediately more comfortable in my own surroundings, you know

1) The Quantitative Interview Schedule

Interview Procedures:
ECB Attainment of Expertise Project

Introduction

This interview is designed to provide information about your long-term involvement in Cricket plus background information about your developmental sporting history. It consists of four major sections. The first section focuses on demographic information. The second looks at your general participation in sporting activities. The third section deals with developmental milestones and performance indicators in cricket throughout your development. The final section centres on unstructured cricket activities and time commitment to different aspects of these activities. The whole interview due to last 2 hours, however I will be helping us keep on track as were going through to ensure I don't take up any more of your time than is necessary.

1. Demographic and Family Information

Personal Details
<Fill in PERSONAL DETAILS on Excel>

2.1 Homeplace Throughout Development

Please can 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. I'll go through this age by age, from 6 to 24.

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

<Fill in HOMEPLACE Table 1.1 on Excel>

1.2 Education Throughout Development

Please can you now tell me (from earliest to most recent) 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 practice sport.

< Fill in SCHOOLING Table 1.2 on Excel >

2. Activities throughout the Lifespan

Table 2.1 Organised sports

2.1 Involvement in Organised Sports

Essentially, in this section, we would like to focus on *all* organized sports that you were involved in throughout your development – these are activities that were organised and led by an adult (i.e., coach, teacher, parent etc.) in diverse settings such as competitions, practices, and when receiving instruction. Looking back over your entire life please tell me *(interviewer write down sports in the first column of chart 1.1)* any type of "organized" sporting activities that you engaged in on a regular basis. I am interested in finding out about your involvement in any type of organized sports (i.e., basketball league, football league, swimming lessons, school sports, etc.), including cricket. Please list to me ALL the sports you participated in starting as early as age 4 and continuing up until age 40.

<In chart 2.1, fill in the first column, "organised sports">

For each sport mentioned, 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 basketball, but only played for an organised team from age 6 to 12, put X's in boxes corresponding to ages 13-40. Do this for each sport listed.

<In chart 2.1, put an X for each age that interviewee was NOT involved in the listed sports, individually>

Let's go through each sport individually across the relevant ages for a typical week for your sporting involvement. For sports that you were engaged in throughout several years it is important that you tell me about any changes in the number of hours in a typical week as you progressed in your development. Starting with cricket, please can you tell me the number of hours you were engaged in structured practice during a typical week at 'age x' and how many months of the year this would have been over, crucially. *(interviewer writes down the number of hours of cricket practice for the specified age).*

<Fill in hours/week and months/year for each sport listed in Chart 2.1>

Of the 'x number of hours cricket practice per week' at this age, what proportion of your practice (as a percentage) would you say was spent in your first discipline at this age?

<Fill in % of practice time spent in specialty>

During a typical week at the same age, how many hours of structured competition were you involved in?

<Fill in competition hrs/week>

Please can you tell me how many months of the year you would be competing in this way for?

<Fill in months/year>

Of the ‘x number of hours cricket competition per week’ at this age, what proportion of your involvement in competition (as a percentage) would you say was spent in your first discipline at this age? Based on who I’ve interviewed so far, the best way to recall this is probably the proportion of overs bowled in your typical matches at this age.

<Fill in % competition time spent in specialty>

3. Developmental Milestones, Performance Indicators and Maturation in Cricket

In this section of the questionnaire I would like you to focus specifically on your development in cricket. I would like to get a sense of your development in cricket by assessing different milestones that may have contributed to your achievement. 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:

3.1 Developmental milestones
< Fill in on Excel>

3.2 Performance Indicators
<Fill in on Excel>

3.3 Performance indicators and Maturation
<Fill in Table on EXCEL across then down>

For the next stage, I am going to be asking you questions about your practice history across a number of specific developmental stages (ages). The aim, is to measure your level of performance and challenges faced as you developed as a cricketer at different ages/stages. The first developmental stage will be when you were **14** years of age, I will now ask you a series of questions associated with this age and the teams you played for, and then we will repeat this process for a number of other fixed ages up until age **40**. There may be some of these teams which may not apply to you, in which case just let me know

Think back to age **14**. Could you please tell me the highest level of cricket representation you were playing for school? E.g., was it for your school year or for England schools? *(Interviewer reminds interviewee that these questions correspond to when they were 14 years of age and subsequently reports the age group that corresponds to each of the levels listed above in table 3.1).*

<Fill in highest level of representation>

Which age group did you represent?

<Fill in Age Group>

Next, please can you tell me how old you were when you were **<u>first</u>** selected into this school age group when you were **14** years of age *<u>(interviewer individually lists the levels of cricket that the interviewee had previously reported engaging in at the age noted. Simultaneously, the interviewer reports the age that corresponds to each different age group team in table 3.1).</u>*

<Fill in Age First Selected>

Please could you tell me what your main role was when representing this team (i.e., what your selection was based on). E.g., spin bowler/batsman?

<Fill in role>

I would now like to ask you about the level of challenge you faced at this age group, (specifically, level of challenge in this case is the combination of competition for places and the standard of opposition faced at each representation level and associated age group of your cricket). Please rate the level of challenge from being 0 % = Extremely easy; 100% = Extremely challenging. *<u>(Interviewer lists individual cricket age groups the interviewees had previously reported playing in and simultaneously reports the level of challenge noted for each age group in table 3.1).</u>*

<Fill in challenge>

Next, I would like to ask you about your ability compared to your peers at this school age group. Specifically, in your opinion, at what age did you become one of the best in your main role on your team at U… age group for … representation level? *<u>(Interviewer lists the necessary age groups/levels and then reports the age stated by the interviewee for each age group/level in table 3.1).</u>*

<Fill in one of best main role >

Similarly, I would now like you to tell me in your opinion, the age at which you became the best in your main role on your school team at this age group? *<u>(Interviewer lists the necessary age groups/levels and then reports the age stated by the interviewee for each age group/level in table 3.1).</u>*

<Fill in best main role>

Please tell me your age when you achieved your first noteworthy/significant positive performance at this age group. This could be related to an individual milestone or your contribution to the team at a significant period, and is completely open to your interpretation… *(Interviewer reports the age provided for the specified age group/level of cricket in table 3.1, interview recording will also be used to collate what perceptions of early significant performance are categorized as).*

<Fill in first significant performance>

I would now like you to tell me about your physical size in comparison to your team mates at this particular age group. Please tell me if you were of greater physical size (G), smaller (S) or equal I to your team mates/cricket peers. *(Interviewer records the responses related to physical size on chart 3.1).*

<Fill in physical size >

Based on your perception of what good vs poor facilities looked like during your development, please tell me whether the facilities which you practiced with at the U… age group for … representation level of cricket were poor (P), below average (BA), adequate (A), good (G) or excellent (E). *(Interviewer lists the cricket levels associated with the age groups relevant to the interviewee and then reports interviewee's perceptions of facilities in table 3)*

<Fill in facilities>

In a similar vein, based on your perception of good and poor practice, I would like you to tell me about the quality of coaching you received from your principal coach (most contact time) at the U… age group for … representation level of cricket. Please rate this as poor (P), below average (BA), adequate (A), good (G) or excellent (E). *(Interviewer lists the cricket levels associated with the age groups relevant to the interviewee and then reports interviewee's perceptions of coach competency in table 3)*

<Fill in coach competency>

Lastly, for this section, I would like to explore the development time (in months) that you missed as a player due to prevalence of injuries and nature. Please note that these can be cumulative, therefore feel free to take some time to think about this. For simplicity, we will record injuries at ages only rather than across each team you represented, starting at the age of **14**. *(Interviewer reports prevalence of injury in months for age 14 in table 3.1).*

<Fill in injury time>.

Interviewer repeats above subsection for each fixed level and age listed in Table 3.1 (17/20/24/28/32/40)

4. Unstructured Activity in Cricket

In this last section, I would like to explore unstructured activity you may have engaged in over the years, starting with sport generally before moving on to cricket specific activity.

First of all, how old were you when you first became regularly involved in any form of unstructured sport (e.g., in the back garden, or down the park)?

We are now going to go into more detail for the different unstructured/unsupervised activities that you have participated in cricket over the years. As in previous sections, we'll go through this according to age, year by year.

I will be asking you about the following activities:

Definitions:

1. **Unsupervised cricket play:**

   Any cricket related playing activity that is not structured and usually for fun/enjoyment either by yourself or with a group

2. **Unsupervised cricket practice:**

   Group practice without a coach (any practice where *no coach is present* but *you and one or more players* are practicing together).

   Independent practice without a coach (any practice where *no coach is present*, no-one else is practicing with you, but you are *practicing on your own*).

3. Reading about cricket
4. Watching cricket on TV
5. Going to watch cricket LIVE

Don't worry about trying to remember these, we can over them again whenever needed, I'll go through them one by one.

Anything Else…

Is there anything else that you can think of that might be helpful in understanding your developmental journey to becoming an established County player/ England International, that we have not discussed?

<Fill in unstructured activity in cricket>

Supplementary Information: Chapter 4

‘Separating the Great from the Good: Optimising Challenge Key in the Development of England’s Greatest Batsmen?’

The aim of this supplementary document is to present:

1) Additional evidence pertaining to the ‘Method’ section contained within the manuscript, to further assist with future replication.

2) The quantitative interview schedule.

1) Method Information

Measures

Table. Overview of the theoretical domains explored within the ‘Attainment of Batting Expertise Interview Schedule’.

Note. N = 658 Features collected for analyses from within these sections.

Structured Batting Interview	
Section 1: Demographic Information • Birthdate • Birthplace • Homeplace • Parental sporting history & achievement • Parental coaching experience • Sibling order effect • Schooling type and experiences • Academic achievements & milestones	**Section 2: Developmental Sporting Activity** • Volume of cricket activity (play, practice & competition) • Number & type of general sports • Prevalence of deliberate play & deliberate practice • Sport & cricket ages (accumulated experience) • Early cricket specialisation vs. sport diversification • Batting specialisation age • Linearity of development in cricket (academy/county teams inclusion & exclusion frequency)
Section 3: Developmental Milestones & Performance Indicators • Highest level of cricket representation by ages 16, 18 and 22 • Age selected for all representation levels • Level of technical & psychological challenge • Time taken to achieve significant performances • Age became teams’ best/one of best batsmen • Perceived quality of coaching and facilities • injury time across defined age periods	**Section 4: Nature & Microstructure of Practice** • Deliberate play & deliberate cricket activity • Physical fitness activity • Mental skills training • Vicarious learning • Conveyance of instruction • Blocked & random & constant & varied batting practice • Blocked & random & constant & varied bowling delivery types & methods • Decision making/execution difficulty • Context & anxiety specificity • Internal & external foci of attention (& nature) • Intrinsic & extrinsic feedback • Constraints & prescriptive coaching approaches

2) Quantitative Interview Schedule, Figures, and Appendices

Interview Procedures:

ECB Attainment of Batting Expertise Project

Introduction

This interview is designed to provide information about your long-term involvement in Cricket 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 cricket 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 cricket 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 swiftly, and I don't take up more of your time than is necessary.

1. Demographic and Family Information

<u>Personal Details</u>

<Section 1 – Demographic Family>

<u>Homeplace Throughout Development</u>

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>

<u>Education Throughout Development</u>

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

<u>Involvement in Sports</u>

<Table 2: Involvement in Sport>

In this next section, we would like to focus on sports that you were involved in throughout your development – this includes all sports 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 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. *<u>(Interviewer place an "X" in any of the boxes corresponding to ages that interviewee was NOT involved in the sport listed)</u>. 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 cricket 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 Cricket. Firstly, starting from when you began playing cricket at age __, can you define when the (1) preseason, (2) midseason, and (3) off season were at 'X' age. 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 cricket >

Now can you recall a typical week for your cricket involvement at this age and tell me the number of hours you were engaged in cricket practice across the (1) preseason, (2) midseason, and (3) the off-season periods that we just defined. Please bear in mind that practice in this case is outside of competitive matches and does not include s+c/fitness work. Practice could mean any of the following; individual practice without a coach, individual practice with a coach, team practice without a coach, team practice with a coach, plus any other type of cricket practice that you may have experienced.

< Table 2 Fill in practice hours/week for X sport listed>

Now, still at age __, I'd like you to tell me the number of hours of structured cricket competition you engaged in during a typical week at (1) preseason, (2) midseason and (3) the off season.

< Table 2 Fill hours in competitive matches for Cricket >

<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 12, 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 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 for when you were between 6 and 12 years of age.

< Table 2.1 Fill proportion of Deliberate Play and Practice between ages 6 and 12 >

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 >

3. Developmental Milestones, Performance Indicators and Maturation in Cricket

<Table 3 - Performance at different ages>

In this section of the questionnaire I would like you to focus specifically on your development in cricket. I would like to get a sense of your development in cricket 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 challenges faced as you developed as a cricketer at each stage specified. The first developmental stage will be by age 16. I will now ask you a series of questions associated with this age group cricket, and then we will repeat this process for by 18 cricket and finally your cricket by 22 (having become senior).

Firstly, by 16, could you please tell me what age you were when you were **first** selected to play at the highest level for the following representation levels of cricket, 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 16/by 18/by 22** years of age and subsequently reports the age that corresponds to each of the levels listed in table 3).*

- ➔ School
- ➔ Club
- ➔ County 1st XI
- ➔ County 2nd XI
- ➔ Regional
- ➔ England

<Fill in Age Group>

I would now like to ask you about the technical challenge of playing at this level when you were first selected at age __. E.g., thinking about decision making and stroke production aspects; for someone playing up an age group the technical challenge might be producing the same stroke to deliveries that have gone from 75 mph to 85 mph. 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 cricket age groups the interviewees had previously reported playing in and simultaneously reports the level of challenge noted for each age group in table 3).*

<Fill in Technical Challenge>

I would now like to ask you about the psychological challenge of playing at this level when you were first selected at age _. Using the same example of going from facing 75 mph to 85 mph for someone playing up age groups against physically bigger players, the psychological challenge in this case might be the fear of getting struck on the head by the ball. To do this, please rate challenge from 1 – 10, with 1 being the easiest rating and 10 being the most challenging rating.*(Interviewer lists representation level and age selected)*

<Fill in Psychological Challenge>

Next, I would like to ask you about your ability compared to your peers at each cricket representation level. Specifically, in your opinion, at what age did you become one of the best batsmen on your team at U… age group for … representation level? *(Interviewer lists the necessary age groups/levels and then reports the age stated by the interviewee for each age group/level in table 3).*

<Fill in one of best batsmen>

Similarly, I would now like you to tell me in your opinion, the age at which you became the best batsman on your team at U… age group for … representation level? *(Interviewer lists the necessary age groups/levels and then reports the age stated by the interviewee for each age group/level in table 3).*

<Fill in best batsman>

Please tell me your age and the rough number of innings it took before you achieved your first noteworthy/significant positive performance at this age group. This could be related to an individual milestone or your contribution to the team at a significant period, and is completely open to your interpretation…Some examples might include achieving your first 50, first 100, or your first successful run chase to win a big competition *(Interviewer reports the number of innings detailed for the specified age group/level of cricket in table 3, interview recording will also be used to collate what perceptions of early significant performance are categorized as).*

<Fill in first significant performance columns>

I would now like you to tell me about your physical size in comparison to your team mates at this particular age group. Please tell me if you were of greater physical size (G), smaller (S) or equal (E) to your team mates/cricket peers when initially selected onto this team. *(Interviewer records the responses related to physical size on Table 3).*

<Fill in physical size >

Based on your perception of what good vs poor facilities looked like during your development, please tell me whether the facilities which you practiced with at the U… age group for … representation level of cricket were poor (P), below average (BA), adequate (A), good (G), very good (VG) excellent (E). *(Interviewer lists the cricket levels associated with the age groups relevant to the interviewee and then reports interviewee's perceptions of facilities in table 3)*

<Fill in facilities>

Based on your perception of good and poor practice, I would like you to tell me about the quality of coaching you received from your principal coach (most contact time) at the U… age group for … representation level of cricket. Please rate this as poor (P), below average (BA), adequate (A), good (G), very good (VG), or excellent (E). *(Interviewer lists the cricket levels associated with the age groups relevant to the interviewee and then reports interviewee's perceptions of coach competency in table 3)*

<Fill in coach competency>

Lastly, for this milestone, I would like to explore the development time (in months) that you missed as a player due to prevalence of injuries by age 16. Please note that these can be cumulative, therefore feel free to take some time to think about this. By age 16, 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 practice 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 by 16, by 18, and by 22 years of age and simultaneously reports prevalence of injury for each in table 3 and records nature of injury).

<Fill in injury time/nature>.

Interviewer repeats the above section for by age 18 and, finally by age 22

< Section 3.1 – List of Questions on Excel>

Milestones/Obstacles

<Section 3.1>

Finally, for this section, I would like to get a sense of your development in cricket 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.

4. Practice Activities in Cricket

What follows is a section in which we want to trace your involvement in the different types of practice possibilities during your cricket 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 cricket activity across each of the three age milestones we focused on in the previous section. *(Interviewer reminds interviewee of the three different age milestones; Ages 16, 18 and 22.*

MILESTONE 1: 16 Years old

Firstly, let's start with when you were playing cricket at 16 years of age. If I refer to your responses in section 2 of this interview (refer to table 2 and look for where the most hours of practice are listed for Cricket at age 16; pre, mid, or post?), I can see that at 16 you stated that most hours on practice were in the ……….season. So, I'd like you to consider the rest of this section in line with a typical week's practice at that point of the season when you were aged 16, which may include any of the following; individual practice without a coach, individual practice with a coach, team practice without a coach, team practice with a coach, plus any other type of cricket 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 16 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.

Physical Fitness
<Table 4.1b>

Still thinking about that same typical week in the …… season, how many hours would you spend on specific physical fitness/conditioning training? This could also include any specific fitness sessions you did during your cricket training, or any of the other sports you may have been playing at age 16 in the …. season.

Non-physical practice hours per week breakdown
<Table 4.1c>

O.k., now considering your typical week in the ……..season when you were 16, 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 4.1c Interviewer subsequently records mental skills training hours >

<u>Vicarious Learning</u>

I would now like you to recall how many hours during the typical week you engaged in learning through watching cricket (e.g., watching cricket on T.V., watching other cricketers' practice and/or playing in order to increase you own skill).

< Table 4.1c Interviewer subsequently records vicarious experiences hours >

<u>Conveying of Information</u>
<Table 4.1d>

Now, I'd like to find out about what your physical cricket 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, team practice without a coach, team practice with a coach, plus any other type of cricket 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 16, 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

SHOT SELECTION (FIGURE 1 & FIGURE 3)

I'm interested in your practice structure and I've got a grid here that I'd like to go through with you. Specifically, I'd like to focus on your shot selection, we'll come onto deliveries you faced later. But for now, I'm talking purely about what your shot selection looked like at this age. If we are going to run over our allotted time, it's going to be because of this section, so I'm going to try and keep it as tight as possible. We need to start by putting percentages on this line here, and then in each of these boxes, all relating to your batting practice sessions and I'll guide us through this.

Blocked/Random

I'm interested in finding out about the proportion of time you spent:

(a) Practicing a shot repetitively in a block period before moving onto another and then another shot.. and so on.
(b) The practicing of different shots that are mixed up, randomly if you like…
(c) Anything different that might have happened in-between

So, let's go back to the start, to times during batting practice where you'd be practicing shots in isolation in blocks, for fixed periods of time… What percentage of the time would batting practice have looked like this at age 16?

What percentage of the time would you have practiced different shots that are mixed up, randomly if you like, meaning that generally no one shot would be the same?

OK, so you have ___ % of your batting practice left that is not filled in at the moment. Do you have an idea what the other percentage would have looked like?

Prompts for interviewer:

Was it always that random, or would there be some of the time where you practiced 2 or 3 of the same shots together before moving onto a different shot? If so, how often would it be like that __%?

Where you practiced shots in overs down here, were there times where you might have practiced in mini overs (i.e., 4 or 5 of the same shot) before moving on to a different type of shot in that session? If so, how often would it be like that __%?).

How Random? (Number of Shots)

Going back to the time times where you'd practice different types of shots in a mixed up, random fashion… How many shots would you typically practice together during sessions like this?

<***Shots are typically defined as;*** *Leave, Front foot defensive (Block), Back foot defensive shot, Cover drive, On drive, Straight drive, Leg glance, The pull, The sweep, Paddle Sweep and the cut*>

How Blocked? (Number of Shots)

Going back to the time times where you'd practice practicing a shot repetitively in a block period before moving onto another and then another shot.. and so on.

How many shots would you typically practice in isolation during practice sessions like this?

Constant/Varied

Of the time where you have reported __ % as:

(a) Practicing shots repetitively for block periods of time - ___

What percentage of the time would this practice have involved you intentionally playing shots roughly to the same place, or where shots might have had the same loft or same pace (and so was fairly consistent) compared to times where shots would be hit to a different area, or have different loft or pace (and so was quite varied)?

(b) ** IF APPLICABLE ** To 'this' bit of your batting practice in between, - __

What percentage of the time would this practice have involved you intentionally playing shots roughly to the same place, or where shots might have had the same loft or same pace (and so was fairly consistent) compared to times where shots would be hit to a different area, or have different loft or pace (and so was quite varied)?

(c) The practicing of different shots that are mixed up, randomly if you like…

What percentage of the time would this practice have involved you intentionally playing shots roughly to the same place, or where shots might have had the same loft or same pace (and so was fairly consistent) compared to times where shots would be hit to a different area, or have different loft or pace (and so was quite varied)?

How Constant is Constant?

Where you have stated that you intended that aspects of your shots would be fairly consistent for periods (meaning that the area you would hit to, loft or pace was consistent)… To what extent did each of these 3 aspects remain consistent when practicing your shots like this?

How Varied is Varied?

Where you have stated that you intended that aspects of your shots to be varied for periods (meaning that the area you would hit to, loft or pace was different)… To what extent did each of these 3 aspects vary when practicing your shots like this?

DELIVERIES FACED <FIGURES 2 & 3>

For this next section, I'd now like to focus on the deliveries you faced at age 16 during practice during a typical ___ week in line with your batting practice that we've just been through. Again, I'll be keeping us on track with time here.

Deliveries – Blocked/Random

I'm now interested in finding out about what the deliveries you faced looked like for each of these batting practice proportions we've just been through. I'll be asking you about the proportions of your batting practice (listed on this grid) and whether you faced any of the following types of deliveries (to make up 100% of the deliveries you faced):

(a) Throw downs by a coach or another player
(b) Bowling machine deliveries that would bowl a type of delivery in overs ((or longer))
(c) The same bowler type (e.g., an off-spin bowler) bowling overs at you repeatedly
(d) The same bowling type bowling single deliveries (e.g., multiple off-spin bowlers taking it in turns to bowl at you) one after the other
(e) Different types of bowlers who would bowl randomly one after the other, meaning that on the large part, each delivery was different and was completely random

So, let's go back to the start, to times during batting practice where you'd be *practicing shots in blocked drills down here*, typically what % of these sessions at this age would you face:

(a) Throw downs by a coach or another player
(b) Bowling machine deliveries that would bowl a type of delivery in overs ((or longer))
(c) The same bowler type (e.g., an off-spin bowler) bowling overs at you repeatedly
(d) The same bowling type bowling single deliveries (e.g., multiple off-spin bowlers taking it in turns to bowl at you) one after the other
(e) Different types of bowlers who would bowl randomly one after the other, meaning that on the large part, each delivery was different and was completely random

Deliveries – Constant/Varied

When considering the deliveries faced for this batting practice as a whole, in terms of line, length and pace of these deliveries, to what extent were deliveries set up to either (a) Feed your shots or (b) Get you out, on the whole?

When I talk about line, length and pace here, I mean what the deliveries were purposefully aimed to do, regardless of natural variation (i.e., in a machine, or due to a person's bowling ability).

<Interviewer can deduce from the breakdown in delivery percentages as to the extent that deliveries were generally feed, get you out, or both>

Proportion of Bowler Types

Thinking about your batting practice where each shot you played would generally be different (highly random):

What proportion of these bowlers were pace, finger spin and wrist spin?

What proportion of all those bowlers would be right handers, compared to left handers?

Proportion of Bowler Types

To what extent would these bowling proportions be the same when you practiced your shots in isolation (in blocks)? *If not the same:*

What proportion of these bowlers were pace, finger spin and wrist spin?

What proportion of all those bowlers would be right handers, compared to left handers?

Difficulty (Decision Making)

I'd like to ask you how difficult you found shot selection in each of the scenarios we've been through at age 16, taking into account the deliveries you were faced with. To do this, we'll go for a rating of 1-10, with 1 being where you had to make no decisions, meaning that the level you had to think was non-existent (extremely easy) and 10 being where you had to make lots of decisions, meaning that the level you had to think was maximal (extremely challenging).

Difficulty (Execution)

To what extent did your shot outcome match your intention when practice looked like this? Again, if we go with a rating of 1-10, with 1 being that your shot outcome would match your intention all of the time and 10 meaning that your shout outcome never matched your intention.

<u>SPECIFICITY AND DIFFICULTY OF PRACTICE</u>
<Table 4.1e>

Context Specificity:

I would now like you to rethink about what practice was like in your typical week when you were 16. 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 scoring scenarios that were likely to occur in competition. Then perhaps the technical aspects of practice would involve gaining experience on wickets with different lift and turn if competition involves different type of wickets. Or maybe you were facing the same bowlers in practice who you were likely to be facing in the next match. Please also try to recall situations where these examples might have happened 'accidentally', for example (during a typical pre-season week) you may have been practicing with more than one club and thus been exposed to more than one wicket, or types of bowlers.

Based on the types of examples just spoken about, what proportion of your practice was similar to competition at age 16? (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 'match scenario' sessions typically were at 16? *(Interviewer records difficulty on Table 4.1e)*

< Table 4.1e fill in Difficulty >

Anxiety Specificity:

Finally, in regard to practice matching competition, for your typical week when you were 16 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., being made to sit out the next practice session if you failed to score 20 or more runs, being moved down the batting order in the next competitive match if you failed to produce 10 consistent executions of a particular shot in the nets, or were made to perform some mundane job for the good of the team. 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 16? *(Interviewer records difficulty on Table 4.1e)*

< Table 4.1e Fill in Anxiety Specificity Difficulty >

<u>Pressure Induced Specificity</u>
<Recorded>

Finally, in regard 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 (FOA)</u>
<Table 4.1f>

O.K., I now want you to spend a little more time thinking about what your typical week was like when you were 16. 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., your coach may have asked you to focus on your hands or asked you to move your feet and your head in a certain direction when performing …..or you may have focused on keeping your elbow high).
2. Situations where you focused on the outcome of your movements (e.g., when the coach asked you or you decided to focus on the swing of the bat….the flight of the ball… where the ball was to be hit to…).

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 4.1f>

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 swing of the bat, the rotation of the wrists, or the position of head etc.*) or whether they were more holistic and simply focused on the technique as a whole (*e.g., attack the ball, move fast, move smoothly, feel my body moving fast, feel myself rotating powerfully*). *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>

Intrinsic/Extrinsic Feedback
<Table 4.1g>

Again, thinking back to your typical week when you were 16, 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 shot 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 there 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 >

Constraints/Prescriptive Learning Approaches
< Table 4.1h>

Finally, for your typical week at age 16, I would like to understand how often practice encouraged you to learn batting 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 shot in a technically correct fashion together with lots of feedback and guidance about how to adjust this technique on future attempts.

Task based coaching typically involves creating situations where learners are encouraged/forced to find solutions to batting scenarios through exploration and discovery. In a little more detail, the batting scenarios are created by

1. Manipulating the task (such as the conditions imposed by the coach (e.g., you can't hit the ball over the top, or maybe you can only score in the air)
2. Manipulating the environment such as the playing surface, the weather conditions (dry, damp), and the availability of sensory information (i.e., the vision, hearing, or 'feel' of the player).
3. Manipulating you as a player, perhaps by limiting your movement (e.g., batting one handed, wearing a helmet that restricts vision, the use of ropes or elastic bands).

In constraints-based coaching, when these types of manipulations have been imposed by the coach, or maybe even by yourself, your batting 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 16 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 4.1h)*

< Table 4.1h Fill in proportion of coaching approaches >

<u>Key Transitional Point</u>
<Excel Sheet>

Finally, I would like you to think about whether there was a key learning experience that took place at age 16? It doesn’t necessarily have to be at 16 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 REPEATS SECTION 4 FOR AGES 18 AND 22.

Figure 1. Shot Selection

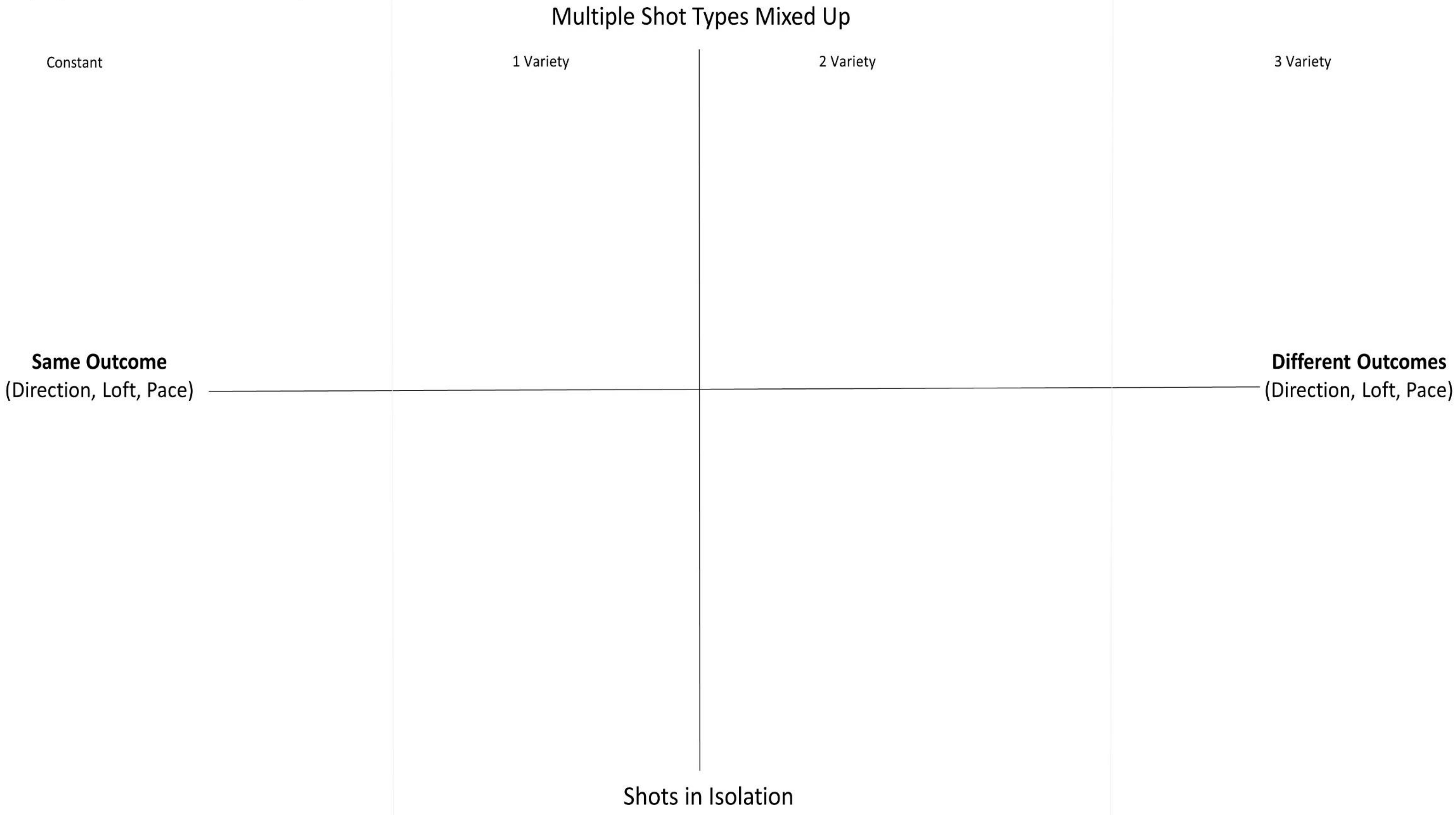


Figure. 2 Bowling Deliveries Faced

Throw downs =
Machine =
Same bowler type – overs =
Same bowler type – different balls =
Different bowlers- different balls =

Throw downs =
Machine =
Same bowler type – overs =
Same bowler type – different balls =
Different bowlers- different balls =

Throw downs =
Machine =
Same bowler type – overs =
Same bowler type – different balls =
Different bowlers- different balls =

Throw downs =
Machine =
Same bowler type – overs =
Same bowler type – different balls =
Different bowlers- different balls =

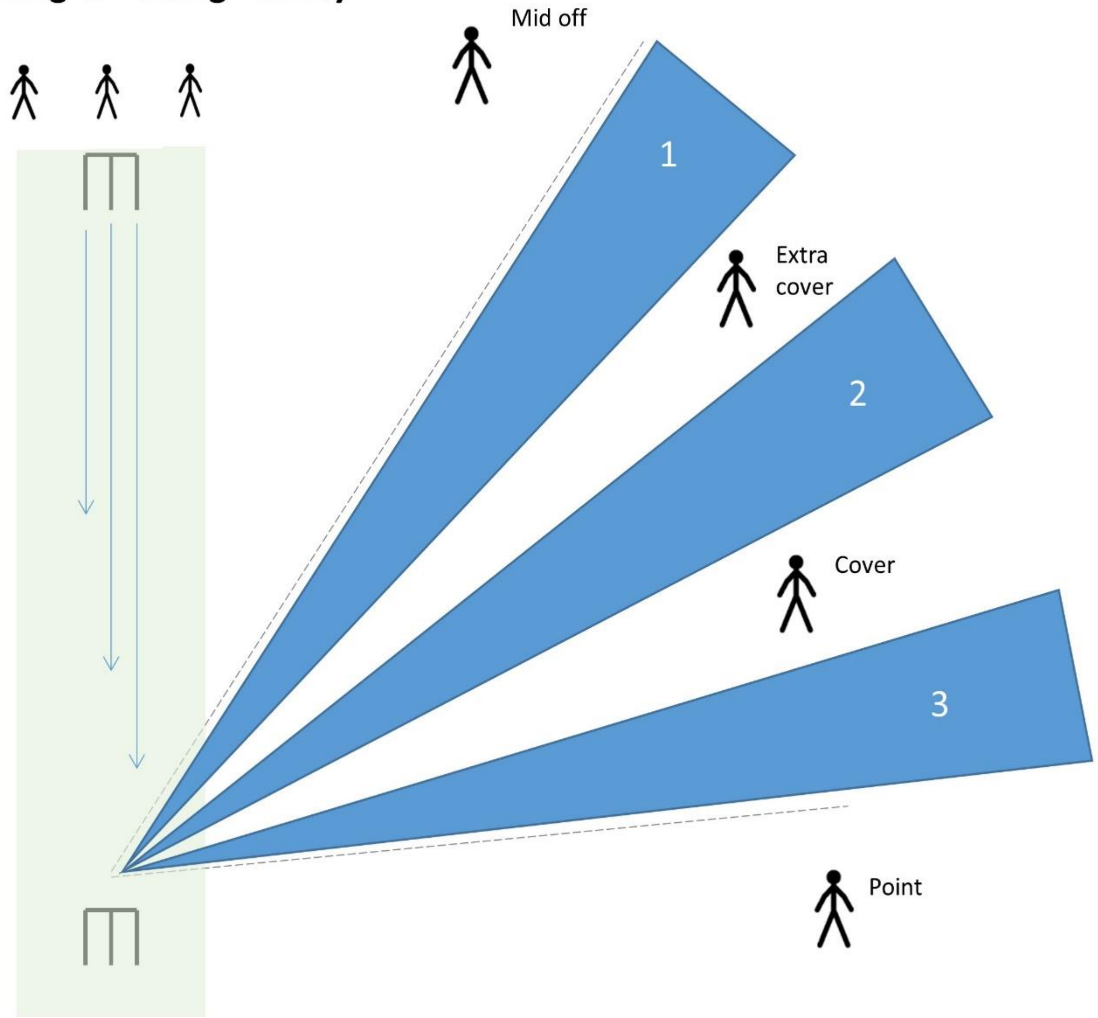
Throw downs =
Machine =
Same bowler type – overs =
Same bowler type – different balls =
Different bowlers- different balls =

Throw downs =
Machine =
Same bowler type – overs =
Same bowler type – different balls =
Different bowlers- different balls =

Deliveries Aiming to Feed (%)

Deliveries Aiming to Get Out (%)

Figure 3. Examples of Bowling & Batting Variety



APPENDICES

Appendix 1

PATTERN RECOGNITION ANALYSIS

Procedures For Sports Science:

Phase 1 – WEKA

Written by Ben Jones and Lew Hardy

With advice from Lucy Kuncheva *(Comp Science)*

Contents

Guide to Pattern Recognition Procedures

PHASE 1 - WEKA (Short-Term Recommendation)

Context: This document is the product of several meetings between Ben Jones, Lew Hardy and Lucy Kuncheva. During these meetings, it became apparent that a flaw existed in the existing pattern recognition procedures previously adopted within SSHES. In short, these are due to a flaw in WEKA's leave-one-out method during feature selection. These flaws result in inflated accuracy within classification models, meaning that final classification accuracy may be optimistically biased. Consequently, an obligatory health warning should be included in manuscripts which adopt phase 1 protocol, outlining that the (optimistic) classification accuracy obtained using the current dataset may not reflect the true accuracy observed in different/unseen samples. Nevertheless, phase 1 is recommended for the time-being as the gold-standard protocol for use within the school, until phase 2 is finalised over the time. This is because Lucy's phase 2 solution depends on some as yet unpublished research that she has been conducting.

Step 1: Preparing the Excel File

	A	B	C	CP
1	Birth_Quarter	Place_of_Birth_Size	#_of_Siblings	Class
2	2	2	1	1
3	3	3	0	0
4	4	3	2	1
5	3	2	3	0
6	1	2	2	1
7	3	2	2	0

The data should have r rows and c columns of numbers.

Each row is an **object** (called also data point, instance, example), and each column is a **feature** (called also attribute, variable). 1

The top row contains the feature names.

Last column is the **class label** (criterion variable). It need to be dichotomous

Step 2: Cleaning the data

Ensure that your data does not have missing values. If your data does have missing values, apply a pre-processing method. For example, if you have too few objects and a lot of features (wide data), consider removing the features with missing values. If you have "tall data", consider removing the objects with missing values. There are many methods for inserting replacements for the missing values. One very crude method is to use the mean of the column (feature). However, we would strongly urge caution in replacing missing values.

Step 3: Scaling the data

Many pattern recognition methods (but not all) will assume that your features are measured in the same units. For example, in image processing, the features are often the pixel luminosity – they are all measured on the same scale. The two typical ways to scale *numerical* data are:

(1) Standardise. This converts each feature into a variable with mean 0 and standard deviation 1. To do this, find the mean and standard deviation of each column. For each value in the column, subtract the column mean and divide by the column standard deviation (you can use SPSS to do this for you).

(2) Scale between 0 and 1. For this scaling, identify the minimum (min_c) and the maximum (max_c) in each column. Then, for each cell (value x), calculate (x – min_c) / (max_c – min_c).

Thus, the minimum of each column will be 0, and the maximum will be 1. *Always say which method of scaling you have used when reporting results.*

Step 4: Creating an ARFF file for WEKA

There are several ways to do this, for sake of demonstration, we have used Notepad ++ (below); we would recommend downloading this free upgrade rather than using the standard notepad version. This is because WEKA will often flag up any typos/missing data on specific line numbers that must be rectified before you can upload the data, and Notepad ++ has line numbers listed, whereas the traditional Notepad doesn't. Without line numbers, finding syntax errors can become a painstaking process (to put it mildly), particularly when working with large datasets.

1. We must give our ARFF file a title, which always begins with "@Relation" followed by a space and then our nominated title that describes the data-set. **NOTE** – spaces must always be denoted by "_" where shown to exist in this notepad file.

2. Attribute labels should be pasted immediately underneath the title, preceded by "@Attribute" and a space. it is strongly recommended that you cut/paste the attribute titles from your Excel spreadsheet and transpose them, before pasting them to Notepad. This is to ensure that attribute labels represent their true column of data below, and none get missed out.

93 Factors Initial attempt 2.arff

```
@Relation SPINBOWLERS_DEVELOPMENTAL_HISTORY
@Attribute Birth_Quarter Numeric
@Attribute Spin_Specific_Practice_Up_to_Age_14 Numeric
@Attribute Mean_of_overs_bowled_up_to_First_XI_debut Numeric
@Attribute Cricket_Competition_Hours_Up_to_England_Debut Numeric
@Attribute Age_First_Regular_Involvement_Cricket Numeric
@Attribute Age_Decision_Made_To_Become_Professional_Cricketer Numeric
@Attribute Age_Specialisation_in_First_Discipline Numeric
@Attribute Age_First_Joined_County_Cricket_Academy Numeric
@Attribute Highest_Level_Cricket_Representation_by_Age_14 Numeric
@Attribute Years_Taken_Sig_Perf_Snr_Club_Cricket Numeric
@Attribute Years_Taken_Sig_Perf_County_Second_XI_Debut Numeric
@Attribute Years_Taken_Best_Spinner_First_XI_County Numeric
@Attribute Expertise_Group {1, 0}
@data
0.5 0.5 0.2 0.4 0.2 0.6 0.9 0.8 0.5 0.2 0.7 0.5 1
0.7 0.2 0.2 0.6 0.2 0.6 0.2 0.6 0.2 0.2 0.7 0.2 0
0.1 0   0.3 0.5 0.3 0.5 0.3 0.5 0   0.3 0.1 0   1
0.3 0   0.5 0.8 0.5 0.8 0.5 0.8 0   0.5 0.3 0   0
0.1 0.9 0.7 0.1 0.7 0.1 0.7 0.1 0.9 0.7 0.1 0.9 1
0.2 0   0.7 0   0.7 0   0.7 0   0   0.7 0.2 0   0
0.3 0.8 0.9 0.8 0.9 0.8 0.9 0.8 0.8 0.9 0.3 0.8 1
0.8 1   0.8 0.9 0.8 0.9 0.8 0.9 1   0.8 0.8 1   1
0.4 0.7 0.4 0.7 0.4 0.7 0.4 0.7 0.7 0.4 0.4 0.7 0
0.4 1   0.2 0.3 0.2 0.3 0.2 0.3 1   0.2 0.4 1   1
1   1   0.5 0.5 0.5 0.5 0.5 0.5 1   0.5 1   1   0
0   1   0.6 0.6 0.6 0.6 0.6 0.6 1   0.6 0   1   1
0.5 0.3 0.7 0.8 0.7 0.8 0.7 0.8 0.3 0.7 0.5 0.3 0
0.6 0   0.9 0.9 0.9 0.9 0.9 0.9 0   0.9 0.6 0   1
0.6 0.6 0.2 1   0.2 1   0.2 1   0.6 0.2 0.6 0.6 0
0.8 0   0.1 0.8 0.1 0.8 0.1 0.8 0   0.1 0.8 0   1
0.9 0   0.4 0.9 0.4 0.9 0.4 0.9 0   0.4 0.9 0   0
0.1 0   0.5 0.5 0.5 0.5 0.5 0.5 0   0.5 0.1 0   1
0.2 0.4 0.9 0.4 0.9 0.4 0.9 0.4 0.4 0.9 0.2 0.4 0
0.4 0.5 0.5 0.3 0.5 0.3 0.5 0.3 0.5 0.5 0.4 0.5 1
0.5 0   0.8 0   0.8 0   0.8 0   0   0.8 0.5 0   1
0.6 0.7 0.7 0.2 0.7 0.2 0.7 0.2 0.7 0.7 0.6 0.7 0
0.8 0.9 0.6 0.6 0.6 0.6 0.6 0.6 0.9 0.6 0.8 0.9 0
0.9 0   0.5 0.4 0.5 0.4 0.5 0.4 0   0.5 0.9 0   1
1   0   0.3 0.8 0.3 0.8 0.3 0.8 0   0.3 1   0   1
0.5 0   0.2 0.9 0.2 0.9 0.2 0.9 0   0.2 0.5 0   0
```

3. Following the insertion of attribute labels, we need to tell WEKA that each attribute is "Numeric" in nature.

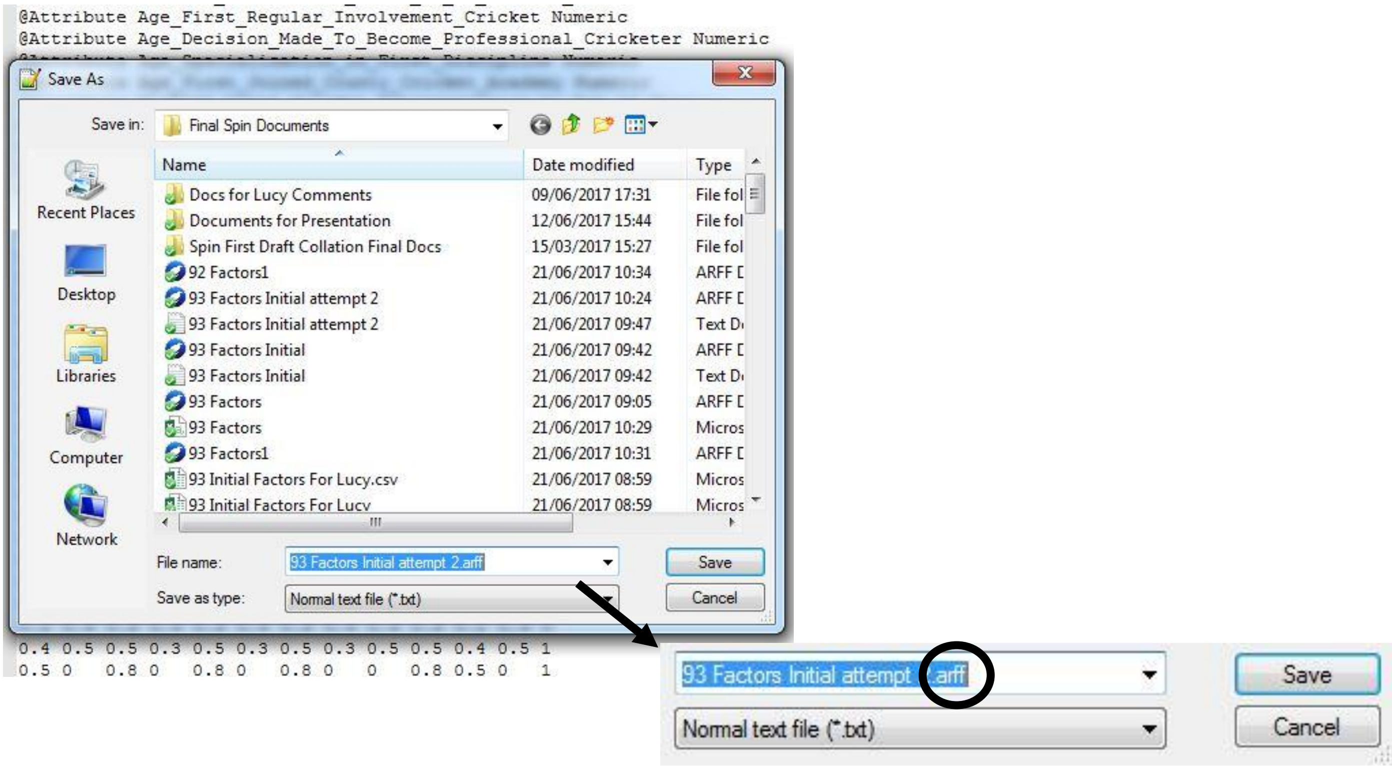
4. The class labels should be included in parentheses following the class label on the penultimate syntax line, i.e., {1, 0}

5. The data from the Excel spreadsheet can then simply be pasted immediately beneath "@data". Each column will correspond to the attribute labels set out above (providing that the steps above have been followed).

6. Each row corresponds to each object, and is terminated with the respective class label (e.g., 0/1, representing elite/sub-elite).

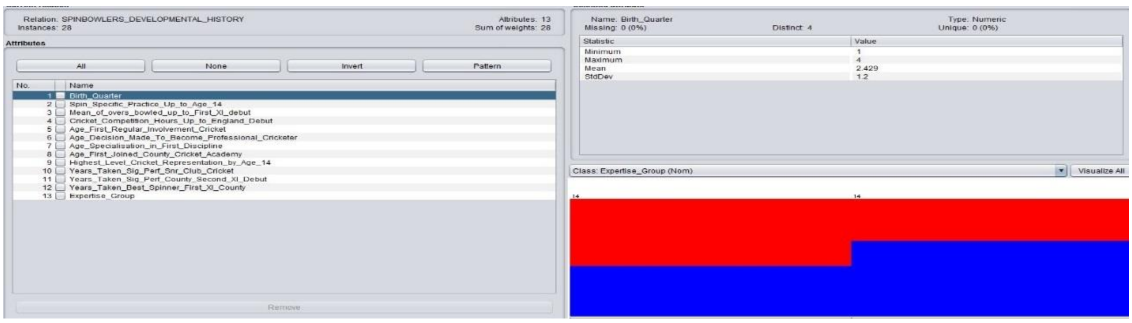
Step 5: Uploading to WEKA

1) Once the data has been prepared, it should be saved as a standard text file, and then saved again as an ".arff" file. The arff file will transform the text file to allow upload to WEKA. The standard text file may be required for modifications required later.



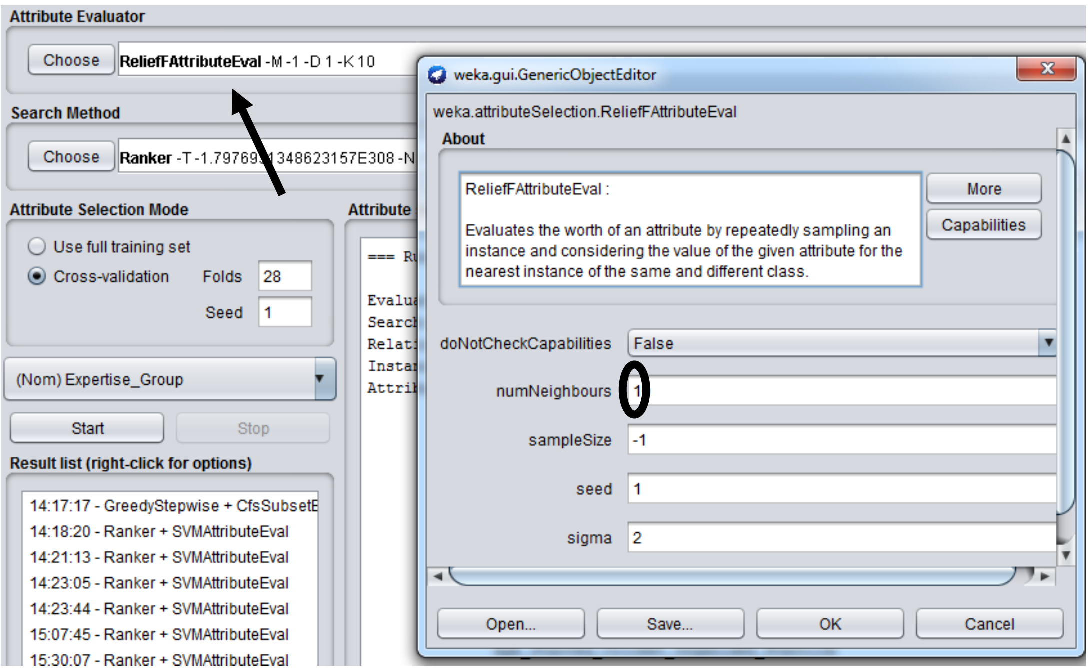
2) Open up WEKA and select "Explorer" at the main menu. Select "Open File" in the top LH corner, manoeuvre to where your ARFF file is saved and open it.

3) Providing that there are no typos in the WEKA ARFF file you have prepared, you should be welcomed with this screen, meaning that your data has been uploaded successfully. *But, note that this very rarely happens first time around…*

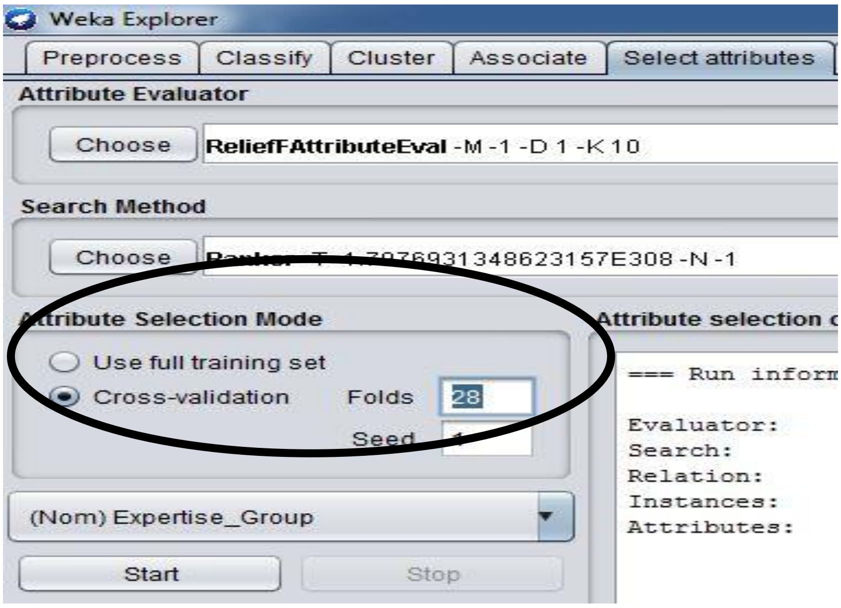


Feature Selection Preparation ("Select Attributes")

The first step in feature selection (FS) is to simply rank how different FS methods weight the importance of the different features. A reasonable starting point is to take the top 20 attributes according to 4 different feature selection methods. Where the same attributes appear in the top 20 for more than one FS method, these can be colour-coded as a visual means of detecting and summing the number of commonalities later. It is recommended that SVM (K= 0), SVM-RFE (K=1), Relief-F (K = 1) and CFS (Default K) feature selection methods are used to rank the features initially. Where K needs to be modified (Relief-F and SVM) do so by clicking each FS method and then replacing the default numerical value that exists in the highest placed box. For example, to use Relief-F (k=1), replace the default "numneighbours" value of 10 with 1. Note that *both* SVM and SVM-RFE are selected by clicking "SVMAttributeEval". Having done this you will see that the default value of k on the top line is 1(SVM-RFE). To use SVM, change the value of k to 0.



The Leave-one-out (LOO) mode should be selected from the “Attribute Selection Mode” by checking the cross-validation box and inserting the total number of objects in your dataset (e.g., 28) into the “Folds” box:



Step 7: Feature Selection Analyses – Individual Rankings

- Use 4 separate methods to rank the features**
- Select the top 20 ranked features according to each FS methods (cfs will not usually give you anywhere near 20, just select whatever it gives you)
- In the dataset we used below, 36 different features sit within the top 20 across the 4 FS methods
- White space equals indicate attributes with no consensus across methods
- The other coloured attributes were selected by at least two different methods

Table 1. Top 20 Feature Rankings According to the 4 Recommended FS Methods (LOO)

Rank	SVM	SVM-RFE	Relief-F	CFS
1	30	30	1	30
2	73	73	71	56
3	56	56	57	37
4	54	54	58	1
5	48	48	67	57
6	1	1	26	49
7	57	57	24	48
8	41	41	43	42
9	62	62	30	
10	25	25	68	
11	67	67	6	
12	38	38	34	
13	37	37	66	
14	55	55	75	
15	22	22	76	
16	50	50	33	
17	53	53	64	
18	87	87	9	
19	43	43	73	
20	93	93	4	

- **# of Features Common across All 4 FS Methods: *3*** *(30, 1, 57)*
- **# of Features Common across 3 of the 4 FS Methods: *9*** *(30, 73, 56, 48, 1, 57, 67, 37, 43)*
- **# of Features Common across 2 of the 4 FS Methods: *20*** *(30, 73, 56, 48, 1, 57, 67, 37, 43, 41, 62, 25, 38, 55, 22, 50, 53, 87, 93, 54)*

****NOTE – SVM and SVM-RFE provide identical feature rankings with this dataset. If this happens, you should replace SVM-RFE with a *different* FS method. We recommend that the Correlation Attribute Evaluator (CAE) FS method be used to replace SVM-RFE in such a scenario. This recommendation has been exercised on the next page.**

Corrected Step 7: Feature Selection Analyses – Individual Rankings

- 4 separate methods used to rank the features
- Pre-defined threshold for ranking features according to FS methods: $n = 20$
- White space equals no consensus across methods
- 42 different features sit within the top 20 across the 4 FS methods

Table 2. Top 20 Feature Rankings According to 4 FS Methods (LOO) – *Using CAE instead of SVM-RFE*

Rank	SVM	Relief-F	CFS	CAE
1	30	1	30	30
2	73	71	56	48
3	56	57	37	57
4	54	58	1	43
5	48	67	57	56
6	1	26	49	1
7	57	24	48	41
8	41	43	42	45
9	62	30		31
10	25	68		37
11	67	6		59
12	38	34		62
13	37	66		25
14	55	75		68
15	22	76		7
16	50	33		32
17	53	64		54
18	87	9		76
19	43	73		74
20	93	4		24

- **Number of Features Common Across All 4 FS Methods:** ***3*** *(30, 1, 57)*
- **Number of Features Common Across 3 of the 4 FS Methods:** ***7*** *(30, 56, 48, 1, 57, 37, 43)*
- **Number of Features Common Across 2 of the 4 FS Methods:** ***16*** *(30, 73, 56, 54, 48, 1, 57, 41, 62, 25, 67, 37, 43, 24, 68, 76)*

In the first instance, we wish to select features based on the prevalence that they appear across multiple feature selection methods top 20 rankings, providing an indicator of consistency. Individual features re-appearing across multiple FS rankings (highlighted) are regarded as predictive in nature, and should be retained for classification. In this regard, it is recommended that a minimum of at approximately *10* common features* and a maximum of not more than 20 common features should be selected across the multiple FS methods, to reduce the danger of overfitting[11]. In this case, *16* features were identified based on a selection criterion of consistency across at least 2 FS methods. These 16 features are shown in *Table 3* below. It is worth noting that, with a 'better behaved' dataset, it is often possible to obtain approximately 10 features that have been selected by 3 different feature selection methods. Under such circumstances one could perform classification analyses on both the larger and the smaller set of features. We can now proceed to classification.

***NOTE: Should the number of features common across FS methods fall below 10, then this is an early indication that the dataset is not robust, and an extra**

---

[11] In **overfitting**, a statistical model describes a random error or noise instead of the underlying relationship, often caused by the selection of features with limited predictive power.

step must then be undertaken to select features. This involves the aggregation of the individual rankings shown in *Table 2* to obtain best agreement across the FS methods. Please proceed to *pages 13-16*, prior to classification, if the aforementioned issue applies to your dataset.

Table 3. The 16 selected features that were common across 2 of the 4 FS methods

Feature Number	Feature Labels
30	Mean Overs Bowled up to First XI County Debut
1	Birth Quarter
57	Highest Level of Cricket Competition by Age 17
56	Highest Level of Cricket Competition by Age 14
48	Age Decision Made to Become Professional Cricketer
37	Cricket Competition Hours up to England Debut
41	Age of First Regular Involvement in Cricket
67	Years Taken to Achieve First Sig. Perf. In 2^{nd} XI CC
73	Years Taken to Become Best Spinner in First XI CC
54	Age First Joined a County Cricket Academy
62	Years Taken to Achieve First Sig. Perf. Snr Club Cricket
25	Spin Bowling-Specific Practice up to Age 14
43	Age of First Involvement in Unsupervised Practice
68	Years Taken to Become Best Spinner in Second XI CC
24	Age of First Organised Spin Bowling-Specific Practice
76	Cricket Play Hours up to Age 14

Step 8: Classification Analyses

So far, we have selected our 16 features according to stringent criteria, and have reached the penultimate stage of pattern recognition analysis, known as classification. This is where we determine the accuracy (%) by which selected classifiers can discriminate between our two classes (elite/sub-elite n the present instance). There is wide recognition in the literature that different classifiers will suit some datasets better than others, given that they use different classification processes, and different algorithms. In this regard, the larger the number of classifiers classifiers that agree on the accuracy of a feature-set, the greater the confidence that can be placed in those discriminating features. Note that leave-one-out must be employed during classification Consequently, multiple classifiers should be explored to measure the initial classification accuracy of the selected feature-set. We recommend the following:

- J48 decision tree classifier: 53.6%
- Nearest neighbour (Lazy learner, IB1) classifier: 85.7%
- Support Vector Machine (SVM) classifier: 78.6%
- Naïve Bayes classifier: 85.7%

This recommendation is based on the fact that these 4 classifiers employ very different approaches. Consequently, we end up with a very holistic outlook on the worth of our 20-feature dataset. At first glance, we can see that the Nearest Neighbour and Naïve Bayes classifiers possess the greatest classification accuracy of 85.7% for the current dataset, indicating that these classifiers successfully predicted the class label (elite/sub-elite) of 24 out of the 28 objects based on the 16 features selected.

Given that the aim of the pattern recognition process is to identify the set of features that will describe the data in the best possible way, we then use a process called Recursive Feature Elimination (RFE), to explore whether we can obtain a more accurate classification using a smaller subset of the features initially selected.

Step 9: Recursive Feature Elimination

The RFE process can make use of a deeper understanding of the subject area to construct logical feature combinations that likely discriminate. This process helps overcome overfitting given how features which amount to noise (and don't contribute positively to the predictive model's accuracy) are removed. We recommend that one of the two options to outlined below is used to identify the feature combination that provides the greatest classification accuracy:

1) **Classify every possible *n* combination of features**
   - E.g., carry out an iterative process which looks to identify the best 14/13/12/ … feature combination until you arrive at an 'optimum' number of features that provide the greatest classification accuracy
   - Due to the time-consuming nature of this process, this is not recommended when working with a large feature-set; e.g., 15 features. However, it will be viable when we move over to Lucy's Phase 2 approach.

2) **Removal of features based on low individual classifier feature weightings**

- This method of RFE is concerned with progressively removing features which possess the lowest weighting within a given classification model until classification accuracy stops increasing or worsens
- Note that not all classifiers provide feature weightings. Consequently, we recommend the use of the feature weightings provided by the SMO (SVM) classifier – see below:

```
BinarySMO

Machine linear: showing attribute weights, not support vectors.

        -0.7211 * (normalized) Birth_Quarter
 +       0.2745 * (normalized) Age_First_Organised_Spin_Specific_Practice
 +      -0.5849 * (normalized) Spin_Specific_Practice_Up_to_Age_14
 +      -1.1629 * (normalized) Mean_of_overs_bowled_up_to_First_XI_debut
 +      -0.6191 * (normalized) Cricket_Competition_Hours_Up_to_England_Debut
 +       0.5399 * (normalized) Age_First_Regular_Involvement_Cricket
 +       0.8554 * (normalized) Age_First_Involvement_Unsupervised_Practice
 +       0.9977 * (normalized) Age_Decision_Made_To_Become_Professional_Cricketer
 +      -1.1344 * (normalized) Age_First_Joined_County_Cricket_Academy
 +      -0.7458 * (normalized) Highest_Level_Cricket_Representation_by_Age_14
 +      -0.6285 * (normalized) Highest_Level_Cricket_Representation_by_Age_17
 +       0.3884 * (normalized) Years_Taken_Sig_Perf_Snr_Club_Cricket
 +       0.6789 * (normalized) Years_Taken_Sig_Perf_County_Second_XI_Debut
 +       0.3993 * (normalized) Years_Taken_Best_Spinner_Second_XI_County
 +       1.0823 * (normalized) Years_Taken_Best_Spinner_First_XI_County
 +      -0.2842 * (normalized) Cricket_Play_Hours_Up_to_Age_14
 +       0.361
```

Initial Classification Accuracy

Pre-RFE:

Feature 30	Feature 1	Feature 57	Feature 56	Feature 48	Feature 67	Feature 37	Feature 73	Feature 43	Feature 54

Feature 76	Feature 24	Feature 41	Feature 62	Feature 25	Feature 68

= 16 Features: SMO (SVM) Classification Accuracy = 78.6%

Final Classification Accuracy

Post-RFE:

Feature 30	**Feature 1**	**Feature 56**	**Feature 62**	**Feature 37**	**Feature 73**	**Feature 54**	**Feature 41**	**Feature 67**	**Feature 25**	**Feature 48**

= 11 Features *(Table 4)*: SMO (SVM) Classification Accuracy = **89.3%**

Table 4. Final classification model containing 11 features (post-RFE)

Feature Number	**Feature Labels**
30	Mean Overs Bowled up to First XI County Debut
1	Birth Quarter
56	Highest Level of Cricket Competition by Age 14
48	Age Decision Made to Become Professional Cricketer
37	Cricket Competition Hours up to England Debut
41	Age of First Regular Involvement in Cricket
67	Years Taken to Achieve First Sig. Perf. In 2nd XI CC
73	Years Taken to Become Best Spinner in First XI CC
54	Age First Joined a County Cricket Academy
62	Years Taken to Achieve First Sig. Perf. Snr Club Cricket
25	Spin Bowling-Specific Practice up to Age 14

If a 'well-behaved' dataset allowed you to select approximately 10 features on the basis of them being ranked in the top 20 for three different feature selection methods, then we recommend that you report three different classification results: 1) the results of the initial classification analysis on those features that were ranked in the top 20 features for two different feature selection methods; 2) the results of the classification analysis for those features that were selected by the more robust criterion of being ranked in the top 20 features for three different feature selection methods; and 3) the results of the final classification analyses performed on the original larger set of features ranked in the top 20 features for two different feature selection methods. In a 'well behaved' dataset, the results of steps 2) and 3) described here should be broadly similar.

(Contingency) Step 7 (i): Feature Selection Cumulative Ranking

You are undergoing this additional step for one of two reasons: **(1)** It was not possible to arrive at a minimum of 10 features based on agreement across two or more Feature Selection methods during step 6; or **(2)** The nature of your research means that you are concerned with selecting a larger number of features (closer to 20) initially, as opposed to a lower number (closer to 10) that have been initially identified in step 6. The following cumulative ranking method allocates an overall points tally to each feature, based on a feature's position among the different Feature Selection methods' rankings, and is concerned with identifying a pool of individual features with the highest predictive power.

An Aggregation is calculated for each feature by summing the rankings of each feature across the three Feature selection methods that give rankings (SVM, Relief-F, and CAE), with a lower points tally reflecting a higher aggregated ranking, e.g., a ranking of 1^{st} + 15^{th} + 19^{th} = 35 points. Where a feature does not appear in one of the FS methods rankings, a score of 30 is allocated to reflect a points tally that is higher than the lowest possible ranking. Alternatively, you can create a cumulative ranking using all four feature selection methods by constructing a ranking for the cfs feature selection method based on the number (or percentage) of folds that a feature is selected for. In the present example, we used the first of these two approaches which gives a very similar set of features to those selected on the basis of being ranked in the top 20 features for two different feature selectin methods.

Table 5. Aggregation* of the 4 Nominated FS Method Individual Rankings found in Table 2

Aggregated Ranking	Features	Total Points Tally
1	30	12
2	1	17
3	57	18
4	56	40
5	48	44
6	37	56
7	41	75
8	67	76
9	73	81
“	54	81
“	62	81
10	25	83
“	43	83
11	68	84
12	24	87
13	71	92
14	76	93
15	58	94
16	26	96
“	49	96
17	42	98
“	45	98
18	31	99
19	6	101
“	59	101
20	38	102
“	34	102
21	66	103
22	55	104
“	75	104
23	22	105
“	7	105
24	50	106
“	33	106
“	32	106
25	53	107
“	64	107
26	87	108
“	9	108
27	74	109
28	93	110
“	4	110

(Contingency) Step 7 *(ii)*: Feature Selection – Identifying a Threshold

This step is also required when selecting features based on the cumulative ranking of FS methods, as observed in the additional step 7*(i)* above. This is the penultimate step prior to classification, and involves the identification of a threshold by which features with the greatest/least predictive power are selected/removed, based on the cumulative ranking. It is recommended that no more than ~20 attributes are retained during FS to reduce the danger of overfitting. The threshold used to determine FS should be identified by reviewing the total rankings points tally *(Table 5).*

Table 6. Possible criteria for selecting/retaining features (the selected threshold is highlighted)

Points Tally Threshold	Qualifying Features (*n*)
90 <	15
100 <	23
110 <	42

In this scenario, features which carry a total of 90 points or less (*n* = 15) are selected, and are listed in *Table 7* below. This threshold abides to the recommendation of selecting no more than ~20 attributes, and subsequently reduces the danger of overfitting. The selection of 15 features also provides us with sufficient leeway to arrive at an 'optimum' number of features, providing the best possible solution to the user. That is, should it later emerge that a number the features selected lack predictive power, then this will be reflected during the initial classification accuracy phase, and such features will be removed during RFE, to provide the user with a combination of features with the highest predictive accuracy.

Table 7. The 15 features retained during FS Based on a cumulative ranking

Feature Number	Aggregation Points Tally	Feature Labels
30	12	Mean Overs Bowled up to First XI Debut
1	17	Birth Quarter
57	18	Highest Level of Cricket Competition by Age 17
56	40	Highest Level of Cricket Competition by Age 14
48	44	Age Decision Made to Become Professional Cricketer
37	56	Cricket Competition Hours up to England Debut
41	75	Age of First Regular Involvement in Cricket
67	76	Years Taken to Achieve First Sig. Perf. In 2nd XI CC
73	81	Years Taken to Become Best Spinner in First XI CC
54	81	Age First Joined a County Cricket Academy
62	81	Years Taken to Achieve First Sig. Perf. Snr Club Cricket
25	83	Spin Bowling-Specific Practice up to Age 14
43	83	Age of First Involvement in Unsupervised Practice
68	84	Years Taken to Become Best Spinner in Second XI CC
24	87	Age of First Organised Spin Bowling-Specific Practice

Now that a sufficient number of features have been selected according to robust criteria, you can proceed to follow the classification and RFE procedures detailed in steps 8 & 9 above.

Appendix 2

PhD Impact and Dissemination Evidence

2a) ECB Research Working Group

Spin Bowling Development Research

Working Group Meeting: **Phase 4**

PRIFYSGOL BANGOR UNIVERSITY

Ben Jones, Raph Brandon, David Parsons, Alun Powell, Mo Bobat, Peter Such

14/08/2018

ECB

Outline of Group Progress to Date

PHASE 1)

THE COMMONALITIES:
EQUALLY ***IMPORTANT*** OR EQUALLY ***IRRELEVANT***?

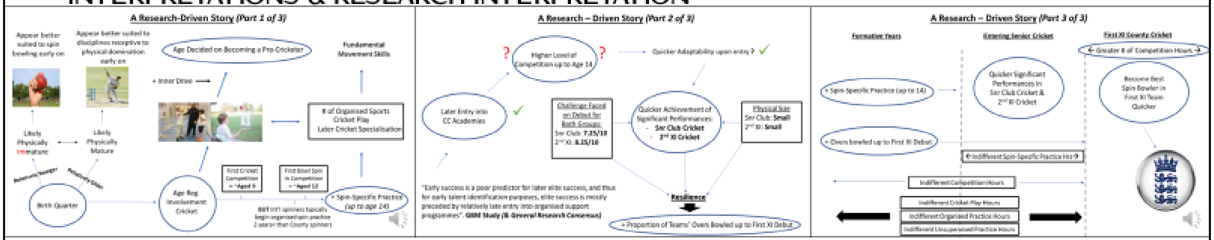
- COUNTY GAME IS A ROUTE THAT MOST   ALL ENGLAND INT' L SPIN BOWLERS GO THROUGH... AND SO WHICH DEVELOPMENTAL FACTORS APPEAR IMPORTANT IN GETTING THERE IN THE FIRST PLACE?
- 19 FACTORS IDENTIFIED AS EQUALLY IMPORTANT BY GROUP
- & GROUPED INTO 3 THEMES

Outline of Group Progress to Date

PHASE 2)

WHAT'S THE STORY?

- ...WHAT SEEMS A LIKELY EXPLANATION FOR THE FINDINGS?
- STORYBOARD PRODUCED BASED ON GROUP DISCUSSIONS   C' FIELD, EXPERT INTERPRETATIONS & RESEARCH INTERPRETATION



Outline of Group Progress to Date

PHASE 3)

Key Recommendations to Enhance the Development of English Spin Bowlers

(...Through Educating Key Stakeholders Across the Following Areas of Development):

[DRAFT]

Phase 4 – Today's Meeting (9-12pm)

- Scrutiny of County Academy Directors / EPP Head Coaches discussions from the recent knowledge sharing sessions.
    - Pull out the **(a)** practical strategies; **(b)** genuine strategic priorities/recommendations, and disregard the irrelevant/impractical
- Finalise means of dissemination and provisional timeline/assigning of roles for

(a) Practical strategies:

- Video > Visual interactive resource > Guide to enhancing spinners development

2b) County Academy Directors Consultation Meeting.

ECB

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COUNTY TALENT PATH... 2m

ECB outlines plans to support County Talent Pathway

Academy Directors from the 18 first-class counties gathered as momentum builds over new plans to support the County Talent Pathway.

"Through our Regional Talent Managers, we will have a much greater presence in the academies and will support the delivery of coach development, parent education, and the Academy Director with their planning and delivery of pathway programmes.

"We're working towards 2025 as the stated goal to have established a game-wide, connected and world-renowned talent pathway.

"This 2018-20 period is all about establishing the foundations, as a key part of the new County Partnership Agreement – and taking in various key strands of Cricket Unleashed such as our South Asian Strategy to increase the reach of our counties."

The day also included a presentation by Ben Jones from the Institute for the Psychology of Elite Performance at Bangor University in North Wales, outlining the findings of a project he has been working on with the ECB's spin-bowling lead Peter Such investigating the characteristics of county and England spin bowlers.

LAST SEVEN DAYS
Most read articles

2c) Plans for ECB Discipline-Specific Coach-Education Video Resource.

RB

Raph Brandon <Raph.Brandon@ecb.co.uk>

Mon 11/02, 18:41

Benjamin Jones; Mo Bobat <Mo.Bobat@ecb.co.uk>

Reply all

Thanks Ben

We will definitely be producing a video with Coach Development so I will keep you posted on getting you involved in that. We will do one for spin as well at the same time.

Thorpey has signed off on these recommendations

Cheers
Raph

Raph Brandon PhD
Head of Science, Medicine & Innovation

2d) Corroboration for PhD Impact on ECB-County Partnership Agreement.

From: Alun Powell
Sent: 15 March 2019 11:02
To: Ben Jones
Cc: Eddie Burke
Subject: RE: CPA and TD Framework Examples for Thesis

Hi Ben,

With reference to the CPA the most obvious impact of your research has been the inclusion within the 'Programme Standards' of definitive contact hours e.g. 10 hours at Academy Level and distinct specialist coaching support at EPP as well as Academy.

Does this help?
Alun.

2e) PhD Findings Forming the 'Programme Standards' of Definitive Contact Hours at Academy Level and Distinct Specialist Coaching Support for Academy and Elite Performance Programmes (EPP).

Emerging Player Programme

Definition:

Individualised programme of support provided by 30 appointed ECB counties to players aged Under 13- 18

Purpose:

To develop basic foundations of future performance through individualised programme of development

Preparation Phase	
Training Frequency	6 hours per week (Including EPP & County Age Group Sessions)
Content	Specialist skill coaching, fielding, conditioning, psychology (group) & nutrition (group)
Staffing	Level 3 Coaches (1:6 ratio), S&C & Psychologist

Competition Phase	
Training Frequency	2 hours per week
Content	Specialist skill coaching, fielding, conditioning
Staffing	Level 3 Coaches (1:6 ratio) & S&C

Academy Programme

Definition:

Individualised programme of support provided by the 18 FCCs to players aged Under 15- 19

Purpose:

To develop robust foundations of future performance through intensive and individualised programme of development

Preparation Phase	
Training Frequency	Minimum of 10 hours per week of cricket related activity (across different environments)
Content	Specialist skill coaching, fielding, conditioning, psychology (individualised), nutrition (individualised) & Personal Development (PCA support)
Staffing	Level 4 Lead Coach & Level 3 Coaches (1:6 ratio), S&C & Psychologist

Competition Phase	
Training Frequency	2 hours per week
Content	Specialist skill coaching, fielding, conditioning
Staffing	Level 4 Lead Coach & Level 3 Coaches (1:6 ratio) & S&C

2f) PhD Findings Contributed to the Talent principles Underpinning the 'What it Takes to Win' model within the ECB's National 'Talent Development Framework'.

Eddie Burke
Wed 20/03/2019 12:01

To: Ben Jones;

You replied on 20/03/2019 12:16.

Action Items

Ben,

I hope you're well.

Please find below, the link to the prototype for the ECB Talent Development Framework.

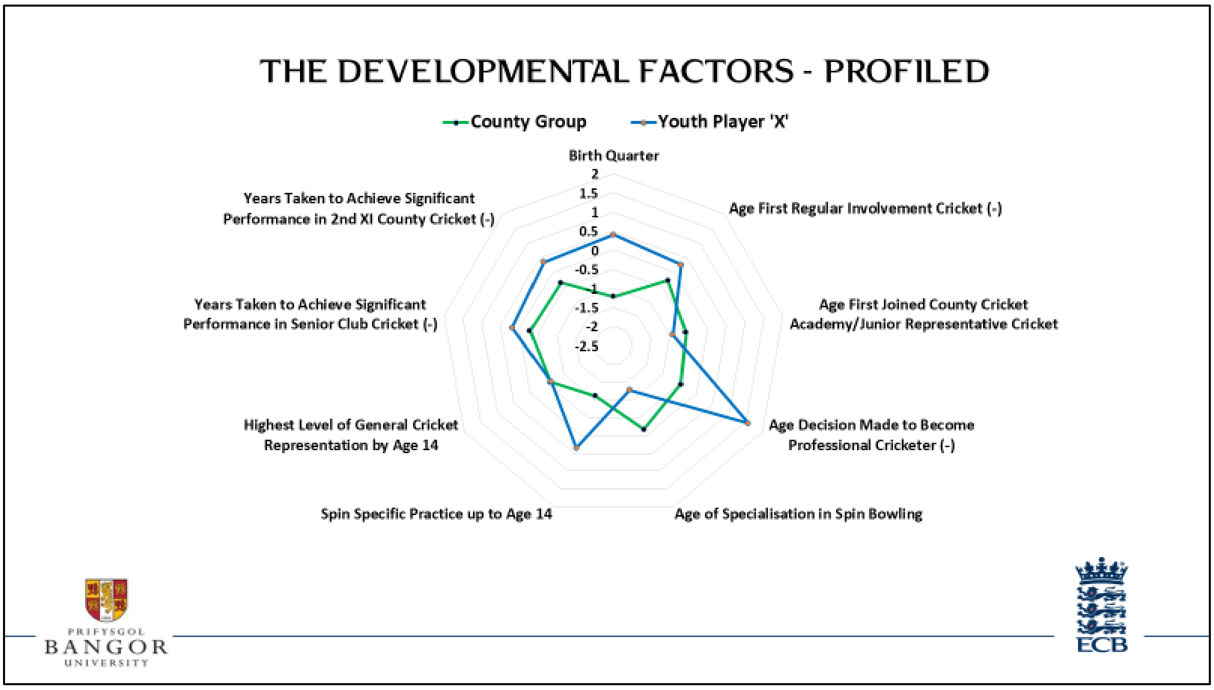
Your PhD findings have contributed to the "WITTW" (what it takes to win model) which will be inputted at a later date.

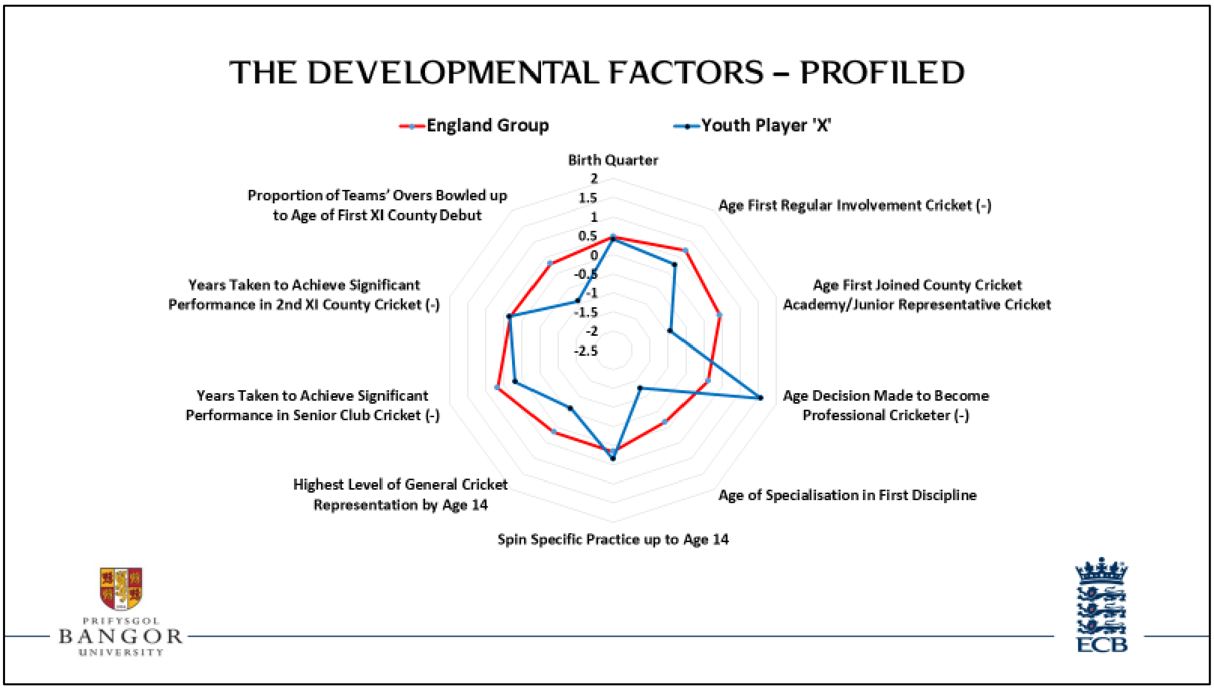
I hope this helps. Although only in an early prototype format, please can you keep this confidential?

Kind regards,

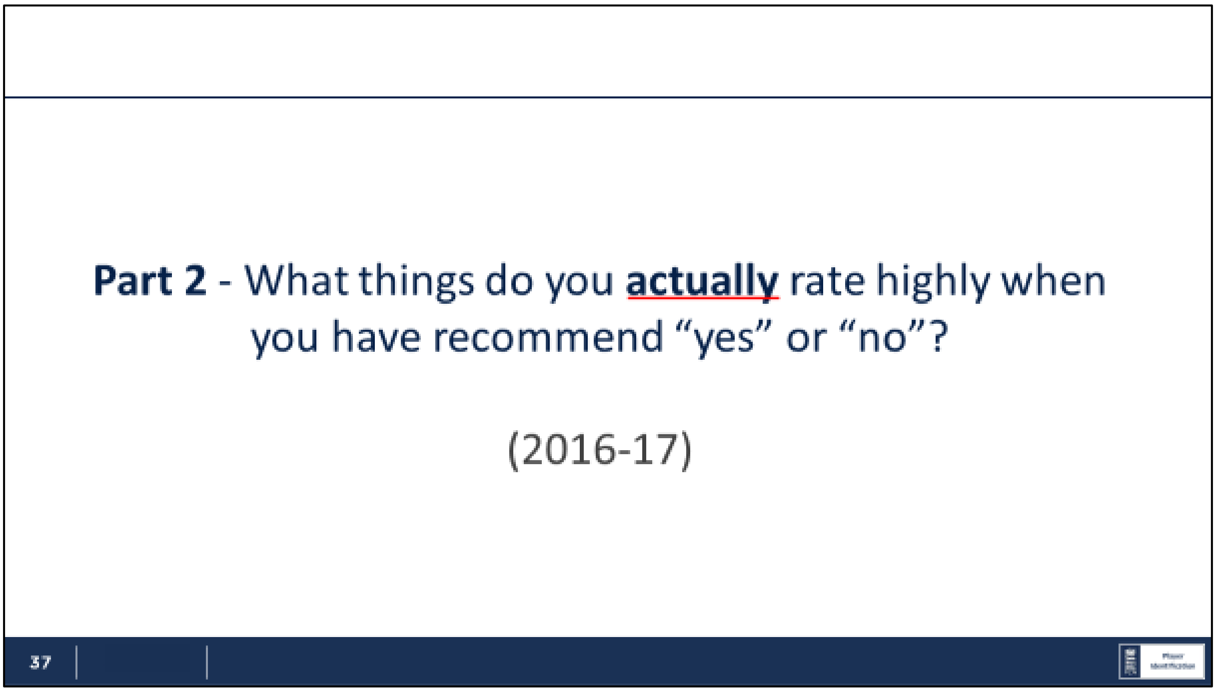
Eddie

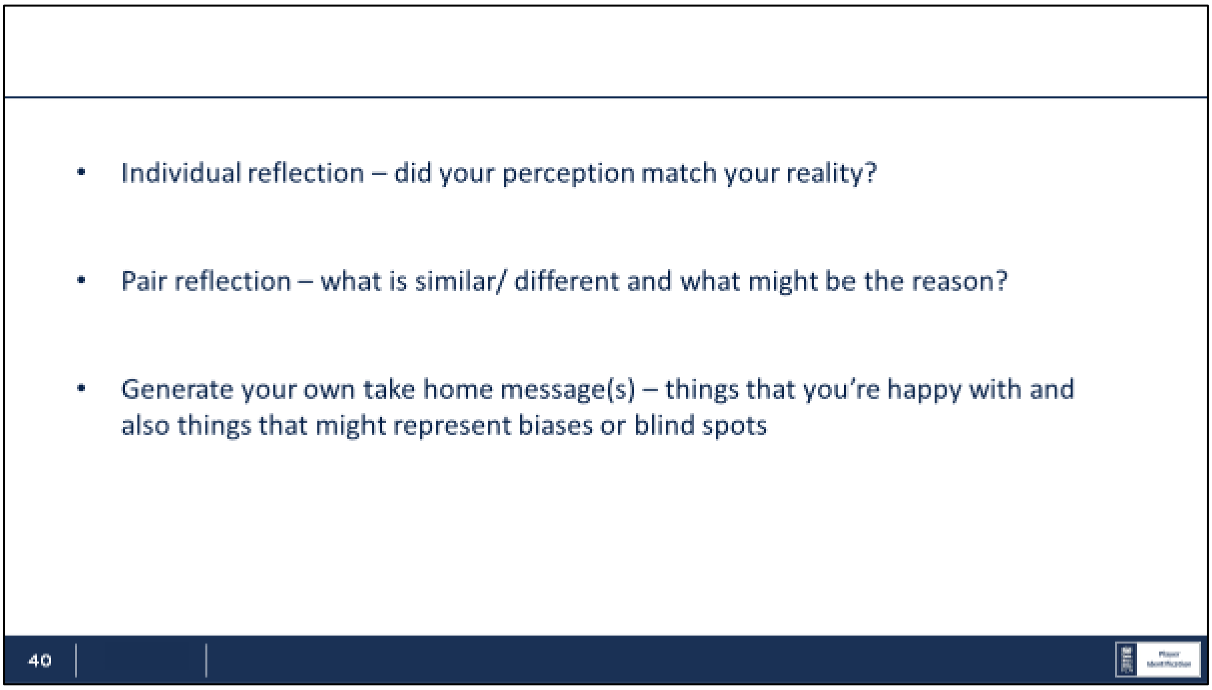
2g) Profiling the Development Trajectories of Youth Cricketers against the Benchmarked Precursors of Elite Expertise.





2h) Identification of individual and group-level Scout biases for CPD self-reflection.





2i) Plans for Filtering and Generating Player Lists for Programme/Team Selection Contention; Introduction of 'National Talent Screening' to Identify High Potential Cricketers; and Prediction of Player 'England Readiness'.

Summary…take-home messages…

- Reintroduce some form of 'talent screening'…esp. for raw attributes
- Multiple eyes/ times is a worthwhile principle…and it appears we've got skilled eyes!
- Consider weighting scouting criteria…but all still important at this stage!
- Utilise untraditional performance stats with a focus on adapting quickly
- Caution with early performance stats, especially at U15 and for CAG batting/ spin
- The whole is greater than the sum of its parts!…screen, scout and analyse stats
- Use findings to support filtering…i.e. generating scouting long-list
- Use findings to aid prediction…i.e. England Readiness assessments
- We still need human decision-making!

70

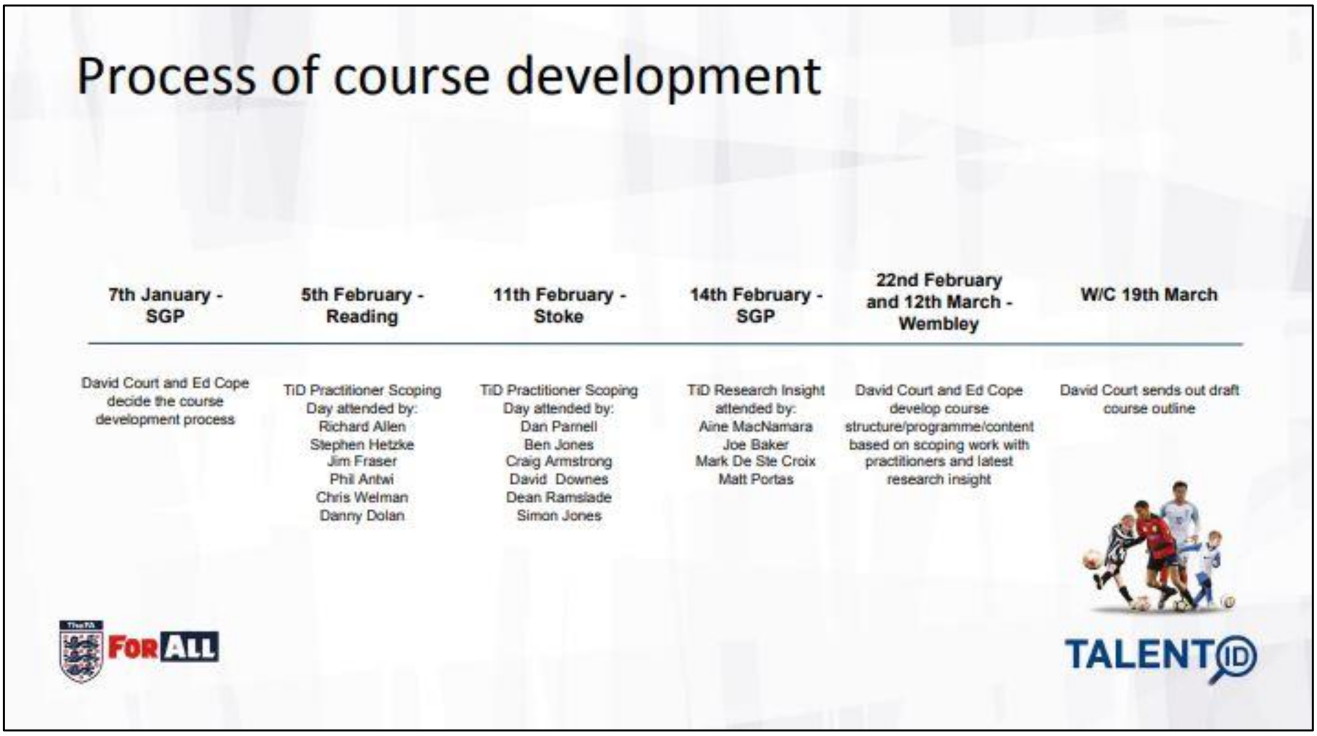
2j) Impact of the research led to the PhD candidate's appointment as Affiliate Tutor for the English Football Association (the FA), delivering insights from the PhD research on the Level 2 award in 'Talent Identification in Football'.

(1) NATIONAL FOOTBALL CENTRE LIMITED

(2) BEN JONES

CONTRACT FOR THE PROVISION OF SERVICES

2k) PhD Candidate Consulted for the Designing of the Curriculum for the English Football Association’s Level 3 Award in ‘Advanced Principles of Talent Identification and Development, held at Stoke City FC, UK.



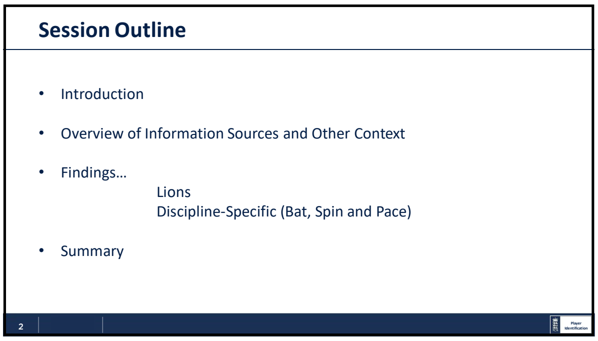
Appendix 3

Searching for the Holy Grail of Talent ID.

Continuing Professional Development Session Delivered to ECB Pathway Officials, East Midlands Parkway, UK.

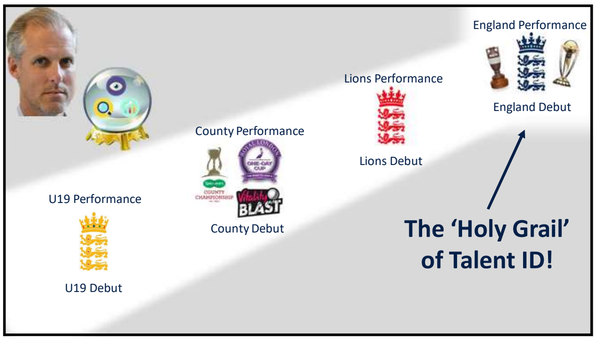
[Sample of Content]

"Ensuring the right quantity and quality of players are selected onto the pathway and into the England teams"
"Searching for the Holy Grail of Talent ID"
Mo Bobat and Ben Jones



Session Outline
• Introduction
• Overview of Information Sources and Other Context
• Findings…
Lions
Discipline-Specific (Bat, Spin and Pace)
• Summary
2

Ed Barney
Ben Jones
Preliminary stages in the validation of a Talent ID model in cricket
Bangor University
2010-15
• Scouting, Predictive Performance Statistics and Talent testing
• Cross-Sectional Analysis
Talent ID and Development
Bangor University
2014-19
• Relative Age Effect – World's best Cricketers
• Developmental Histories – Spin and Batting
• Longitudinal Analysis – Scouting, Performance Statistics and Talent testing
MULTIPLE EYES…MULTIPLE TIMES
MULTIPLE EYES…ON THE RIGHT PLAYERS…MULTIPLE TIMES
3



England Performance
England Debut
Lions Performance
Lions Debut
County Performance
County Debut
U19 Performance
U19 Debut
The 'Holy Grail' of Talent ID!

Information Sources – Scouting

Years = 2011–13

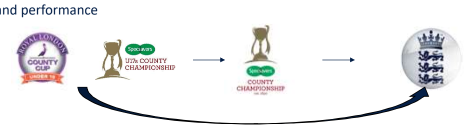
Age groups = U15–17

Initial intent = establish the validity of scouting assessment…not necessarily to inform decisions

Questions have evolved significantly…
2014 (v peers) and 2016 (aligned pathway)

Information Sources – Performance Stats

Initial intent = assess which junior and senior performance statistics predict senior England performance



Defining England Performance…
England batting performance = world ranking, average, no. of innings, total runs scored
England bowling performance = world ranking, average, strike rate, economy rate, no. of innings

Information Sources – Performance Stats

Three retrospective Studies…

1. County age group statistics that predicted senior County performance
2. Senior County statistics that predicted senior England performance
3. County age group statistics that predicted senior England performance

Information Sources – Talent Testing

Initial intent = assist profiling and talent confirmation and also track developmental cricketers through their pathway

Counties were asked to nominate their highest potential cricketers to attend 'EDP Talent Testing'

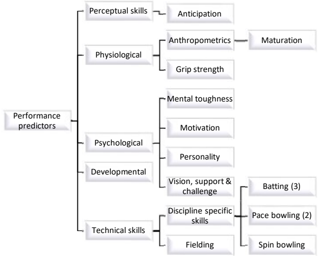
Years = 2011–15 (2011–13)

Age groups = U12–U16 (U16)

Players completed discipline specific skill-based tests, batting assessments (thin bat, batting v pace/ spin), fielding and anticipation assessments, as well as physiological assessments and psychometric profiling

TALENT TEST

Information Sources – Talent Testing



TALENT TEST

Other useful context…

- Age range of sample is 20-24 years old
- We've waited 7 years to analyse the data!
- 183 players within the analysis
- 150+ different analyses
- 360+ hours of dedicated analysis…15 whole days!
- **"Bayesian Pattern Recognition Analysis"** – puts all variables into the same melting pot and provides us with the combination of factors that have the best predictive accuracy

Findings…

1. Lions debut – scouting
2. Batting > FCC debut – combined
3. Spin bowling > FCC debut – combined
4. Pace bowling > U19 debut – performance stats
   FCC debut – Talent Testing

Discussion – small groups…

- Is there anything that surprises you about the findings?
- What do you notice about the combinations of findings?
- What does the absence of traditional junior performance stats tell us?
- How might we use these findings for player ID and/ or coaching?
- What do the player/ squad profiles tell you?

Three groups…

Batting (AF)
Spin bowling (DP)
Pace bowling (JL and RB)

Summary…take-home messages…

- Reintroduce some form of 'talent screening'…esp. for raw attributes
- Multiple eyes/ times is a worthwhile principle...and it appears we've got skilled eyes!
- Consider weighting scouting criteria…but all still important at this stage!
- Utilise untraditional performance stats with a focus on adapting quickly
- Caution with early performance stats, especially at U15 and for CAG batting/ spin
- The whole is greater than the sum of its parts!...screen, scout and analyse stats
- Use findings to support filtering…i.e. generating scouting long-list
- Use findings to aid prediction…i.e. England Readiness assessments
- We still need human decision-making!

13

Appendix 4

Talent Identification & Development PhD Summary:

The 5 Strongest Indicators of Potential.

Session Delivered to ECB National Talent Manager and Regional Performance Managers During Monthly Meeting, Loughborough UK.

[Sample Content]

Talent Identification & Development PhD (2014 – 2018)

Ben Jones

PRIFYSGOL BANGOR UNIVERSITY

The Big Picture

Ed Barney

Preliminary stages in the validation of a Talent ID model in cricket

Bangor University
2010-15

- Cross-Sectional Analysis
  - Scouting
  - Predictive Performance Statistics
  - Talent testing

Ben Jones

Talent ID and Development

Bangor University
2014-18

- Longitudinal Analysis: Scouting, Performance Statistics and Talent testing
- Relative Age Effect – World's best Cricketers
- Developmental Histories of Spin Bowlers
- " & Practice Biographies of Batsmen

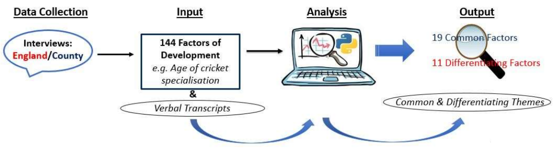
Progress Report

Study	Data Collection	Analysis	Expert Insight *Research*	Expert Insight *Applied*	Internal Sharing	Wider-Game Sharing	Implementation
***1.** Relative Age Effects in World's Best Cricketers*	✓	✓	✓	✓	✓	*N/A*	*N/A*
***2.** Developmental Histories of Elite vs. Sub-Elite Spinners*	✓	✓	✓	✓	✓	*Ongoing*	✗
***3.** Developmental Histories & Practice Biographies of Super-elite vs. Elite Batsmen*	✓	✓	✓	*Imminent*	✗	✗	✗
***4.** Longitudinal Analysis of the ECB's TID Sources (Scouting, Talent Testing & Perf. Stats)*	✓	✓	✓	✓	*Ongoing*	✗	✗

Spin Study: Outline

Spin Bowling

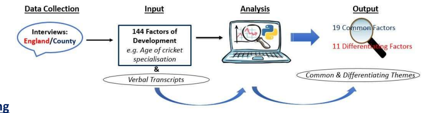
- Which development experiences are **common** *(and likely important)* in becoming a County spinner?
- Which development experiences **differentiate** the spinners who then go on to represent England?



Spin & Batting Studies: Outline

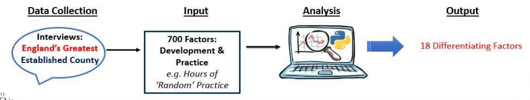
Spin Bowling

- Which development experiences are *common (and likely important)* in becoming a County spinner?
- Which development experiences ***differentiate*** the spinners who then go on to represent England?



Batting

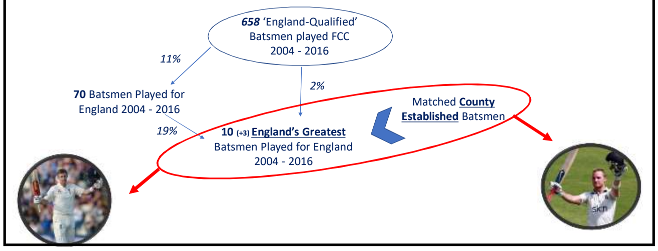
- Which development experiences and aspects of practice *differentiate* England's greatest batsmen of the modern era, from established County batsmen?



The Batsmen: Context

Common Criteria:

- All were 'Batsmen' *(first-discipline batsmen/genuine batting all-rounders/genuine WK-batsmen)*
- Maintained FCC Careers *(Min. 100 innings)*
- Played at their respective highest level of performance between 2004 and 2016 (*FCC/England*)
- Matched on education background, career era & batting position



Longitudinal Study: The 3 Sources of Information

Scouting

Predictive Performance Statistics

Talent Testing

Information Sources – Scouting

Years = 2011–13

Age groups = U15–17

Initial intent = establish the validity of scouting assessment…not necessarily to inform decisions

Questions have evolved significantly…
2014 (v peers) and 2016 (aligned pathway)

Information Sources – Performance Stats

Intent = assess which junior and senior performance statistics predict senior England performance

Defining England Performance…
England batting performance = world ranking, average, no. of innings, total runs scored
England bowling performance = world ranking, average, strike rate, economy rate, no. of innings

Information Sources – Talent Testing

Initial intent = assist profiling and talent confirmation and also track developmental cricketers through their pathway

Counties were asked to nominate their highest potential cricketers to attend 'EDP Talent Testing'

Years = 2011–15 (2011–13)

Age groups = U12–U16 (U16)

Players completed discipline specific skill-based tests, batting assessments (thin bat, batting v pace/ spin), fielding and anticipation assessments, as well as physiological assessments and psychometric profiling

TALENT TEST

England Performance

England Debut

Lions Performance

Lions Debut

County Performance

County Debut

U19 Performance

U19 Debut

The 'Holy Grail' of Talent ID!

PhD 'Current Summary': 5 Strongest Indicators

1. 'Raw' attributes
2. Driven & work harder
3. Faster adapters (and therefore transition quicker)
4. Prolonged exposure to appropriately challenging opportunities (training & match)
5. Perform well more consistently (*indicator <u>and</u> outcome)*

TID Implication = Important to screen, scout and analyse data (non-traditional way).

The 5 Strongest Indicators: *Sources of Evidence**

Ed Barney's PhD:

Cross-Sectional Analysis (1-Year of data)
- Scouting
- Predictive Performance Statistics
- Talent testing

Ben Jones' PhD:

Longitudinal Analysis (3-Years of data)
- Scouting
- Predictive Performance Statistics
- Talent testing

Comparing the Developmental Histories and Practice Biographies of England's Greatest Batsmen & Established County Batsmen

Comparing the Developmental Histories of England & County Spin Bowlers

**Sources of evidence are categorised in the colours above on the proceeding slides…*

PRIFYSGOL BANGOR UNIVERSITY

ECB

PhD 'Current Summary': 5 Strongest Indicators

1. 'Raw' attributes

Cross-Sectional → **Longitudinal**

Ed Barney's PhD – **Talent Testing**

- **Initial Reliability & Validity of Tests**

Early Findings:

U16 TT Data:
5 Batting Tests
2 Bowling Tests

→ **High Ability vs Low Ability** (Pre-Defined Groups) → 5 Batting Tests Reduced to 3 / Thin Bat: Bat-Ball Contact, Pace Bowling Speed

TALENT TEST

Ben Jones' PhD – **Talent Testing**

- **Pathway Progression up to end of 2017 Season**

3-Year Findings:

2011-2013
U16 TT Data:
Batting Tests
Bowling Tests
Anticipation
Psychometrics
Physiology

→ Made First XI Debut **vs.** Remained at Second XI → Thin Bat: Accuracy, Pace Bowling Maximum Speed, Spin Bowling Maximum RPM

TALENT TEST

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PhD 'Current Summary': 5 Strongest Indicators

2. Driven & work harder

Scouting Criteria: **Inner Drive**

Cross-Sectional

Shortlisted vs Selected EDP?

Psychological
Inner Drive

Longitudinal

- Discriminates between *players* selected for Lions, compared to players who remain as First XI cricketers.
- Also shown to discriminate between *batsmen* who have debuted at First XI, compared to those who remain at 2nd XI level.

Developmental Histories: **Practice Volume**

Spin Bowling

- International spinners' sessions contained significantly more spin-specific practice up to the age of 14, compared with the County bowlers.

	Median; England Group	Median; County Group
Spin Specific Practice up to Age 14	50%	0%
Spin Specific Practice up to Age 17	70%	66%
Spin Specific Practice up to First XI CC Debut	81%	66%
Spin Specific Practice up to Age 20	78%	68%

Batting

- England's greatest batsmen undertook significantly more practice volume than the established county batsmen throughout age 16;
  - England did ~ 7 hrs per week vs County of ~ 4 hrs per week across the calendar year.
    - … England did ~ 9 hrs per week during busiest 6-month practice period (i.e., summer/ winter).

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PhD 'Current Summary': 5 Strongest Indicators

3. Faster adapters (and therefore transition quicker)

Cross-Sectional

County age group statistics that predicted snr County performance examples:	County age group statistics that predicted snr England performance examples:
Batting Number of U15 innings to 1st 100 runs Number of U15 innings to 1st 60 runs Number of U17 innings to 400 runs Frequency of scoring U17 centuries	**Batting** U15 Innings taken to accumulate 100 runs → TEST U15 Innings taken to 1st 60 runs → TEST U17 Innings taken to accumulate 400 runs → ODI
Bowling Number of U17 innings to 10 wickets Frequency of taking U17 3 wicket-hauls	**Bowling** U15 Innings → Test U17 Wickets ratio → ODI U17 Innings to 10 wks → Test U17 3 wkt haul ratio → Test

Longitudinal

Spin Bowlers

Compared to Second XI spinners, First XI spinners were likely to:

Weighting
- Have played in more U17s CAG Innings
- Have taken a 3-wicket haul in U17s CAG
- Have taken 10 wickets in 7 innings or less in U17s CAG
- Have taken 20 wickets in U17s CAG

76% Accurate based on current sample

Pace Bowlers

Compared to pace bowlers not selected for Young Lions, Young Lions pace bowlers were likely to:

Weighting
- Have taken a 3-wicket haul in U17s CAG
- Have played in more U15s CAG innings
- Have taken more 3-wicket hauls per inning in U17s CAG
- Have an inferior bowling average in U15s CAG*
- Have taken more wickets per inning in U17s CAG
- Have accumulated 10 wickets in U17s CAG

70% Accurate based on current sample

Developmental Histories

Fast Adapting Players in Senior Cricket

Future international spin bowlers typically report achieving their first significant performance in their Senior Club team and 2nd XI County team sooner.

Future international spin bowlers report becoming first choice 1st XI County team spinner within fewer years post-debut.

Fast Adapting Players in Senior Cricket

Future international batsmen report becoming the best batsmen in their 2nd XI County team, and one of the best batsmen in their First XI County team, at a younger age.

Future international batsmen are more likely to report becoming the best batsman in their First XI County team (outright), and achieve this status within fewer years of debut.

Made First XI (List A) debut at a younger age

Took fewer years to transition from snr Club Cricket to First XI County Cricket

Adapt Quicker

Transition Quicker

PRIFYSGOL BANGOR UNIVERSITY

ECB

PhD 'Current Summary': 5 Strongest Indicators

4. Prolonged exposure to appropriately challenging opportunities (training & match)

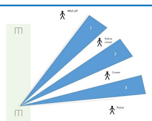
Developmental Histories: **Batting**

- England batsmen reported undertaking a greater volume of random practice that was both more random and varied in nature, than the County players at age 16;
  - More random = practiced more shots together in a random fashion
  - More varied = practiced these shots with more variations *(area, loft & pace)*

Developmental Histories: **Spin Bowling**

- Specific aspects of practice were not measured…

… However, players' perception of how challenged they were across the pathway is a commonality in spin bowlers who get into the County game initially *(Challenge = ~ 7-8/10)*.



PhD 'Current Summary': 5 Strongest Indicators

5. Perform well more consistently > *indicator and outcome*

Competition Volume

< International *Spinners* bowl more overs *(~28% vs 20%)* >

< International *Spinners* experience more competition volume *(~11,000 hrs vs. 8,000 hrs)* >

< International *Batsmen* experience more competition volume *(~1,700 hrs vs. ~1,000 hrs)* >

CAG (U15-17s) — **First XI Debut** (18 - 20) — (23-24)

Performance Frequency & Milestones

E.g.,
- Number of U17 Innings
- # of U17 wickets per inning
- Have taken 20 wickets in U17s cricket

- *Spin:* Achievement of first significant performances *(Snr Club & 2nd CC)* sooner
- *Batting:* Become the best batsmen in 2nd XI County team younger

- *Batting:* Become one of the best batsmen in 1st XI County team younger

- Become best *spinner*/ *batsman* in First XI County team younger

PhD 'Current Summary': 5 Strongest Indicators

1. 'Raw' attributes
2. Driven & work harder
3. Faster adapters (and therefore transition quicker)
4. Prolonged exposure to appropriately challenging opportunities (training & match)
5. Perform well more consistently (*indicator and outcome)*

TID Implication = Important to screen, scout and analyse data (non-traditional way).

Discussion Activity

Question to Consider:

How might these findings influence the talent development framework principles?

Appendix 5

Current Knowledge of Talent Identification and Development.

Handout Distributed at the Blackburn Rovers FC CPD Event.

Bridging The Gap: Developing Potential For Performance

P-Laying the Foundations
(Junior years)

Providing opportunities for experimentation and play during early phases of development by:

1. Allowing players to practice and compete in other sports for as long as is possible
2. Integrating play and multiple sports into training sessions

U16s

U14s

Deliberate **Challenge**
(Adolescence)

Individualised Challenges:

- Positional changes
- Playing up age-groups

Team-based challenges:

- Timely rotation of formations
- Highly varied practice sessions that…
  - ➢ Breed pressure
  - ➢ Game-situation intelligence

Provision for **Support**

Supporting players entering and leaving the academy system

Provision of skills to deal with the challenges & a sufficient support network:

- Player/parent education
- Player mentorship scheme
- Social support & opportunity to overcome setbacks

Produced by Ben Jones twitter **@BenJones0411**

Appendix 6

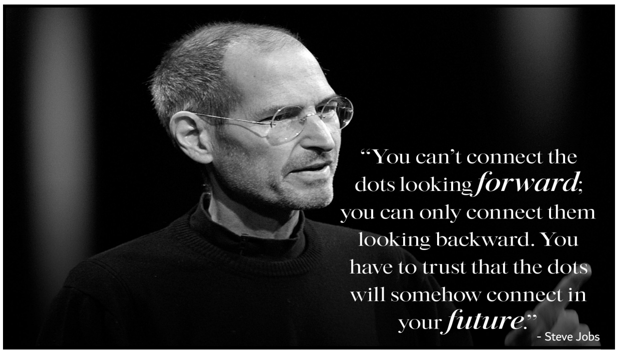
Talent Identification & Development PhD Summary:

The 5 Strongest Indicators of Potential.

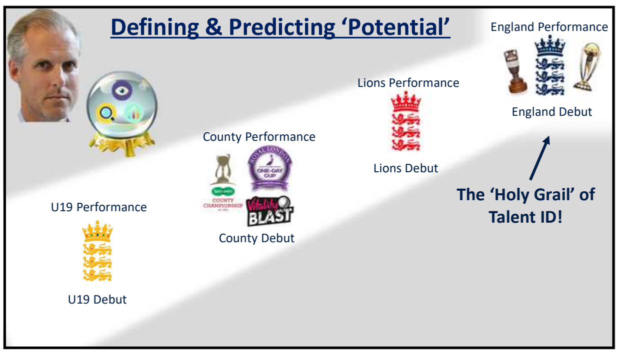
Session Delivered at the ECB's Annual County Academy Directors Meeting, Loughborough UK.

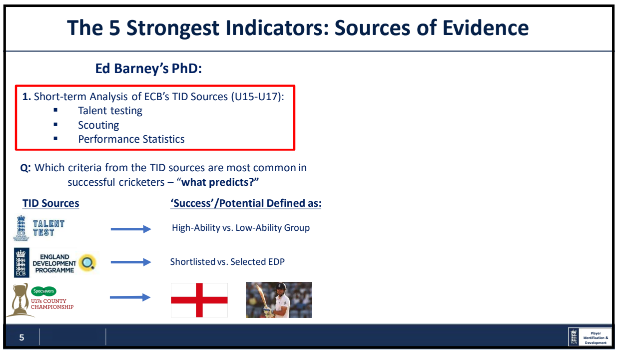
[Sample Content]

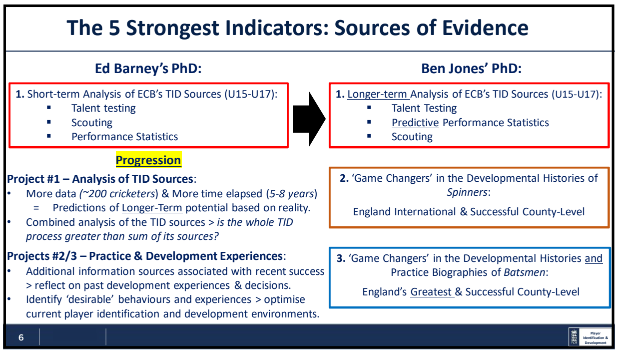

Current PhD Summary:
“The 5 Strongest Indicators
of Player Potential”
Academy Directors Meeting
26th March 2019
Ben Jones

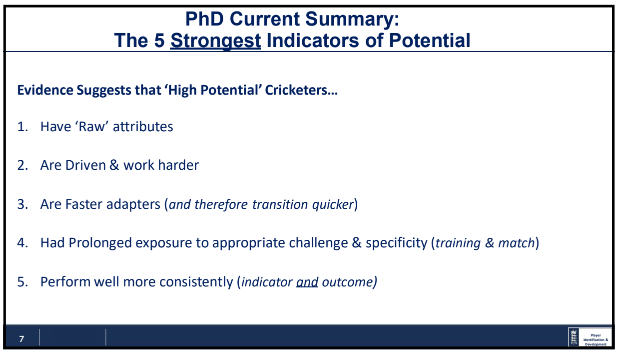

“You can’t connect the dots looking forward; you can only connect them looking backward. You have to trust that the dots will somehow connect in your future.”
- Steve Jobs

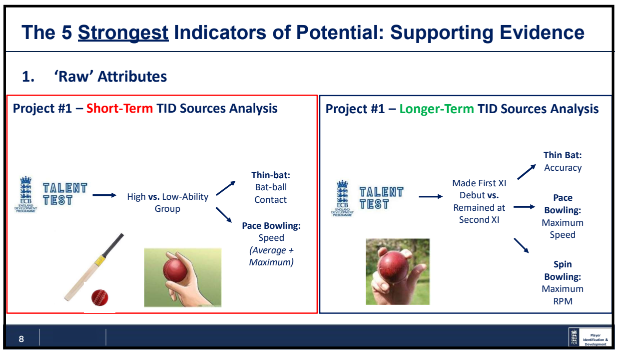

“Ensuring the right quantity and quality of players are selected onto the pathway and into the England teams”
“Searching for the Holy Grail of Talent ID”
October 2018
Mo Bobat and Ben Jones


Defining & Predicting ‘Potential’
England Performance
England Debut
Lions Performance
Lions Debut
County Performance
County Debut
U19 Performance
U19 Debut
The ‘Holy Grail’ of Talent ID!


The 5 Strongest Indicators: Sources of Evidence
Ed Barney's PhD:
1. Short-term Analysis of ECB's TID Sources (U15-U17):
Talent testing
Scouting
Performance Statistics
Q: Which criteria from the TID sources are most common in successful cricketers – "what predicts?"
TID Sources
'Success'/Potential Defined as:
TALENT TEST
High-Ability vs. Low-Ability Group
ENGLAND DEVELOPMENT PROGRAMME
Shortlisted vs. Selected EDP
U17s COUNTY CHAMPIONSHIP
5


The 5 Strongest Indicators: Sources of Evidence
Ed Barney's PhD:
1. Short-term Analysis of ECB's TID Sources (U15-U17):
Talent testing
Scouting
Performance Statistics
Ben Jones' PhD:
1. Longer-term Analysis of ECB's TID Sources (U15-U17):
Talent Testing
Predictive Performance Statistics
Scouting
Progression
Project #1 – Analysis of TID Sources:
More data (~200 cricketers) & More time elapsed (5-8 years)
= Predictions of Longer-Term potential based on reality.
Combined analysis of the TID sources > is the whole TID process greater than sum of its sources?
Projects #2/3 – Practice & Development Experiences:
Additional information sources associated with recent success > reflect on past development experiences & decisions.
Identify 'desirable' behaviours and experiences > optimise current player identification and development environments.
2. 'Game Changers' in the Developmental Histories of Spinners:
England International & Successful County-Level
3. 'Game Changers' in the Developmental Histories and Practice Biographies of Batsmen:
England's Greatest & Successful County-Level
6


PhD Current Summary:
The 5 Strongest Indicators of Potential
Evidence Suggests that 'High Potential' Cricketers…
1. Have 'Raw' attributes
2. Are Driven & work harder
3. Are Faster adapters (and therefore transition quicker)
4. Had Prolonged exposure to appropriate challenge & specificity (training & match)
5. Perform well more consistently (indicator and outcome)
7


The 5 Strongest Indicators of Potential: Supporting Evidence
1. 'Raw' Attributes
Project #1 – Short-Term TID Sources Analysis
TALENT TEST
High vs. Low-Ability Group
Thin-bat: Bat-ball Contact
Pace Bowling: Speed (Average + Maximum)
Project #1 – Longer-Term TID Sources Analysis
TALENT TEST
Made First XI Debut vs. Remained at Second XI
Thin Bat: Accuracy
Pace Bowling: Maximum Speed
Spin Bowling: Maximum RPM
8

The 5 Strongest Indicators of Potential: Supporting Evidence

2. Driven & Work Harder

Project #1
Short-term Finding

Scouting Criteria:
Inner Drive

Shortlisted vs Selected EDP?

Psychological
Inner Drive

Project #1
Longer-term Finding

- Differentiates cricketers of *combined discipline* selected for Lions, compared to players who remain 1st XI cricketers.
- Also differentiates *batsmen* who have debuted for 1st XI County, compared to those who remain 2nd XI cricketers.

Project #2
Spin Bowling Development

- International spinners' practice was significantly more 'spin-specific' up to the age of 14, compared to County spinners.

	Median; England Group	Median; County Group
Spin Specific Practice up to Age 14	50%	0%
Spin Specific Practice up to Age 17	70%	66%
Spin Specific Practice up to First XI CC Debut	81%	66%
Spin Specific Practice up to Age 20	78%	68%

Project #3
Batting Practice & Development

- England's greatest batsmen experienced significantly more practice than county batsmen aged 16:
  - **England** = ~ 7 hrs wk (*calendar yr*) / ~ 9-hrs wk (*busiest 6-month period*)
  - **County** = ~ 4 hrs wk (*calendar yr*) / ~ 6 hrs wk (*busiest 6-month period*)

The 5 Strongest Indicators of Potential: Supporting Evidence

3. Faster Adapters ***(and therefore transition quicker)***

Project #1 - Junior Performance Statistics

Short-term & Longer-term Knowledge Combined:

- Adaptability-related statistics show promise in bowlers, U17s in particular:
  - e.g. for spinners: taking 10 wickets in 7 innings or less in U17s CAG is associated with debuting in 1st XI County cricket.
- 'Traditional' U15s performance statistics are unreliable - especially in isolation.
- Junior batting performance statistics do not currently predict longer-term success.

Project #2 – Spin Bowling Development

- International spinners achieved a first 'significant' performance in Snr Club and 2nd XI County levels sooner than County spinners.
- International spinners became the first choice spinner in their 1st XI County in fewer years than County spinners.

Project #3 – Batting Practice & Development

- International batsmen became the best batsmen in their 2nd XI County, and one of and the best batsmen in 1st XI County in fewer years than County Batsmen.
- International Batsmen also transitioned from snr Club to 1st XI County cricket in fewer years.

The 5 Strongest Indicators of Potential: Supporting Evidence

4. Prolonged Exposure to Appropriate Challenge & Specificity (*Training & Match*)

Project #2 – Spin Bowling Development

- International spinners' practice contained significantly more spin-specific practice up to the age of 14, compared with the County bowlers.

	Median; England Group	Median; County Group
Spin Specific Practice up to Age 14	50%	0%
Spin Specific Practice up to Age 17	70%	66%
Spin Specific Practice up to First XI CC Debut	81%	66%
Spin Specific Practice up to Age 20	78%	68%

- Both International and County spinners felt moderately challenged across their development (*7-8 out of 10*).

The 5 Strongest Indicators of Potential: Supporting Evidence

4. Prolonged Exposure to Appropriate Challenge & Specificity (*Training & Match*)

Project #3 – Batting Practice & Development

England's 'greatest' batsmen experienced a significantly **greater volume** of random practice, that was both **more random**, and **more varied** in nature at **age 16**;

- **More Random** = practiced more shots together in a 'random order'
- **More Varied** = practiced these shots with more shot variations (area, loft & pace)

ENG: 4 Hours vs. CTY: 1 Hour p/wk
Highly Random & Varied Practice

What Does Random & Varied Practice Mean for Coaches?

Highly Random & Varied Practice

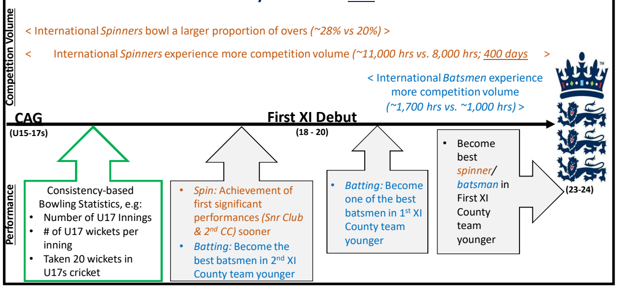
Scoring Shot Practice:
- AKA 'Net Challenges', or 'Nets with targets' or 'Constraints-based practice'.
- ➢ The objective of this is to challenge the player to execute run scoring shots from varied line & length deliveries.

E.g. Take singles and hit boundaries, over the top or on the ground, to specific areas.
- This would require either side arm or real bowling deliveries of various line & lengths and 'field settings' or 'target scoring areas'.
- This type of practice can also be set up as middle wicket practice.

National Lead Interpretation:
- High levels of match play and variety during practice is key during the Pathway ages (13-17 yrs).
  - ➢ 'Purposeful' practice in the nets is essential; Professional players need to display 'self-directed' learning by their early careers.
  - ➢ The more varied the practice – in terms of scoring shot options - the greater the challenge and benefit.

The 5 Strongest Indicators of Potential: Supporting Evidence

5. Perform well more consistently > *indicator* *<u>and</u>* *outcome*



PhD Current Summary:
The 5 <u>Strongest</u> Indicators of Potential

Evidence Suggests that 'High Potential' Cricketers…

1. Have 'raw' attributes *[batting, spin, & pace]*
2. Are driven & work harder *[batting & spin]*
3. Are faster adapters (*and therefore transition quicker*) *[batting & spin]*
4. Had prolonged exposure to appropriate challenge & specificity (*training & match*) *[batting & spin]*
5. Perform well more consistently (*indicator <u>and</u> outcome*) *[batting, spin, & pace]*

Putting into Practice…

<u>Discussion</u>

In pairs, discuss the following indicator of potential:

"*Prolonged exposure to appropriate challenge & specificity (training & match)***"**

What opportunities for 'appropriate challenge' and 'volume' exist in your pathways?

Current Summary of ECB Talent PhD: The 5 Strongest Indicators of Potential

1. Have ‘raw’ attributes *[batting, spin, & pace]*

2. Are driven & work harder *[batting & spin]*

3. Are faster adapters (*and therefore transition quicker*) *[batting & spin]*

4. Had prolonged exposure to appropriate challenge & specificity (*training & match)* *[batting & spin]*

5. Perform well more consistently (*indicator and outcome)* *[batting, spin, & pace]*