The influence of innate talent in the acquisition of sport expertise.

By Toby Staff

Thesis submitted to Brunel University for the degree of Doctor of Philosophy, July 2022.

Table of Contents

Abstract.

This thesis examines the contribution of talent to the acquisition of expertise. First, an experimental task investigates the influence of intelligence, working memory, perceptual speed, psychomotor ability and knowledge components in leading a new sports skill. Then, two studies examine to what degree these variations such as power output and cadence, or energy pathway can be accounted for by the level of focused practice in a particular sport. Utilizing the sports domain, the studies examine factors that contribute to individual difference in performance at three phases of skill acquisition, novice, intermediary, and expert.

The dichotomy of the influence of innate vs. practice factors in expertise has provoked much debate from Francis Galton (emphasizing hereditary genius) to Anders Ericsson (focusing on deliberate practice). Nonetheless, a sports literature review identifies a dominant epistemology for attaining expertise to be practice with the contribution of talent very rarely considered. In order to appraise the influence of talent in attaining a sports skill chapter 3 investigates the impact of psychometric factors on novice participants learning a hockey skill. Results reveal a significant association between performance gains and working memory capacity. Chapter 4 utilizes secondary data analysis to examine the cyclists representing Team GB at 2012 London Olympics. Specifically, a comparison is made between individuals selected using different talent identification measures identify; either (i) accomplished cyclists selected by traditional metrics (race results), or (ii) inexperienced cyclists selected by targeted performance measures (such as power output and VO_2 max). Results show that the inexperienced cyclists became experts quicker than experienced, suggesting that earlier specialized performance practice may not be necessary. Chapter 5 investigates Olympic track and field athletes representing Team GB at London 2012

using secondary data. An athlete's energy requirement (aerobic and anaerobic) was compared for differences in the speed of acquiring expertise, results indicated that athletes in sports more dependent on the anaerobic energy pathway attained expertise quicker than those in sports more reliant on the aerobic pathway.

Overall, these results contribute to a better understanding of talent in motor skill acquisition. They indicate the important contribution of talent to motor skill acquisition and question the dominance of the deliberate practice hypothesis. A greater understanding of the contributions of psychological and physiological components in explaining individual differences in developing expertise is needed. It is argued on the basis of the current research that this requires taking a more theoretically grounded approach to identifying these contributing factors across different sports.

List of papers published during the PhD period.

Peer- reviewed

Staff, T., Gobet, F. & Parton, A. (2020). Investigating the period of practice needed to acquire expertise in Great Britain 2012 track and field Olympic athletes. Journal of expertise. Volume 2: Issue 3.

Staff, T., Gobet, F. & Parton, A. (2021). Early Specialization and Critical Periods in Acquiring Expertise: A Comparison of Traditional Versus Detection Talent Identification in Team GB Cycling at London 2012. Journal of motor learning and development. Volume 9: Issue 2.

Acknowledgements.

I must start by thanking my wife for her support in this endeavor. It was pure academic curiosity that lured me into this PhD, and I have really enjoyed the mentoring process in completing this work. I would like to thank Andy Parton, my first supervisor who has guided me along the way. Continually challenging me to clarify and support my ideas with a positive attitude. He was always at the end of the phone to kick around suppositions or clarify a certain perspective sharing with me his experience and knowledge of psychology.

I am greatly indebted to Fernand Gobet who was the catalyst for me taking my ideas forward. His positive response to our first meeting provided immense encouragement and thereafter he has been a rock, providing support and experience. I would also like to thank Dan Bishop whose sports science knowledge continually challenged me by questioning how my ideas can be applied to sport. Finally, I would like to thank the researchers on my review panels, Survjit Cheeta, Ben Jennings and Andrew Clark they always provided plenty of food for thought during these reviews and were always very positive.

List of figures.

List of tables.

List of Appendices.

1 Chapter 1.

1.1 Introduction.

The basis of becoming an expert is often hypothesized to lie at one of two extremes, either environmental ("practice makes perfect") or genetic determinism ("talent"). Currently, a popular hypothesis is that expertise can be attained by deliberate motivated practice (Ericsson et al., 1993); over the past two decades, it has become the orthodoxy in popular literature that practice is necessary and sufficient to attain expertise if 10 years (or 10,000 hours) of deliberate motivated practice are undertaken (Gladwell, 2009). Thus, it is quite logical to conclude that anyone can become an expert given the requirements of deliberate practice (Gladwell, 2009). In contrast, other researchers have hypothesized that genetically heritable factors are critical in the attainment of expertise (Plomin & Spinath, 2004). These genetically heritable factors can broadly be categorized as underlying either motor-abilities (e.g., anthropometric measures, aerobic capacity, and muscle constituents) or mental abilities (intelligence, perceptual speed, and memory capacity); this view suggests that the capacity to attain expertise is limited by these factors and these limits cannot be removed by practice.

This dichotomy has brought about a tendency for researchers to favour one explanation over another, with deliberate practice proving more popular than talent. Nonetheless, neither of these routes of investigation has produced a general theory that adequately explains how expertise is acquired. This led Ackerman (2014) to conclude, "it is only possible to explain individual differences in elite/expert performance by a combination of genetic and environmental factors, along with their interactions" (p. 10). Therefore, a contribution from both talent and practice will determine the individual differences in performance across the development of expert acquisition.

The current thesis utilizes sport as the domain to investigate the processes underlying the development of expertise. Prior research into how expertise comes about in sport indicates a continuum consisting of contributions from both practice and talent (Rees et al., 2016). However, deliberate practice (Ericsson et al., 1993) has been the dominant framework for studying how skill acquisition unfolds. In many studies, individual differences have been benchmarked by utilizing the speed with which a specific threshold of performance (considered to be expert) is attained; this is termed the “period to excellence” (Staff et al., 2020). Previous research has indicated a wide range for the period to excellence across sports varying from 750 to 20,000 hours (Baker et al., 2003; Baker et al., 2005; Staff et al., 2020). Conversely, investigations into talent have focused on specific factors that predict expertise such as physiological factors and mental traits (e.g. intelligence, psychomotor abilities, and perceptual speed) (Abd El Shakour, Mohamed Fawzy, 2020; Deary & Mitchell, 1989; Paunescu et al., 2013; Staff et al., 2020), although the relative contribution of these factors has not been specifically measured. This thesis hypothesizes that individual differences in the rate at which expertise can be acquired has a contribution from talent.

The psychological literature often uses three phases to characterize the acquisition of expertise (Ackerman, 1990; Anderson, 1996; Bloom, 1985; Fitts & Posner, 1967; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977); these are the novice, intermediary, and expert phases. This thesis will investigate each phase, as the literature suggests that talent may exert a different influence on performance across these stages (Ackerman, 1988).

Sport has produced an abundance of research that focuses on "what experts do" when performing a task to identify components of expert performance that are used to coach performers at the intermediary phase. This top-down approach, that involves particulars of expert performance being identified and coached to novices, has been established historically through trial and error, i.e., each sport has developed its empirical processes. Academic researchers have tended to follow a similar methodology; expertise is explained by studying the outcome rather than the mechanisms leading to it. For example, many researchers have focused on investigating expert anticipatory decisions based on advanced body cues, resulting in the coaching of perceptual cognitive skills that facilitate expertise (Williams & Jackson, 2019). Superior perceptual cognitive skills are dependent upon memory and knowledge (Williams, 2000); however, there is little research into their influence as a precursor to expertise. Therefore, how can understanding what experts do contribute to the comprehension of individual differences in their development towards expertise?

This top-down epistemology has left unanswered some very important questions in our understanding of how we acquire expertise. In particular, the influence of talent and its effect on achieving expertise. The current research examines three phases of skill acquisition and examines factors that impact variations in motor performance at these stages (Chassy & Gobet, 2010; Tucker & Collins, 2012).

Specifically, at the novice phase – what are the influences of mental abilities in motor skill performance? Do superior mental abilities cause faster expertise? Can mental abilities be used as a predictor of future performance? Do mental abilities affect performance similarly or differently across the phases of expertise acquisition? Which mental abilities are they?

At the intermediary phase – what talents can predict future progression? When athletes are selected based on talents, do they attain expertise quicker than experts selected by other methodologies? Are there critical periods during which talent accelerates expertise? Is expertise transferable between sports?

Finally, at the expertise phase – is the speed of motor acquisition dependent upon the skill acquired? How is this affected by the individual talent differences? Why can you attain expertise in some domains faster than others? Is expertise domain-specific, or are there contributions from other domains?

This thesis employs a bottom-up whereby talent is identified and its influence in expertise is interpreted in performance. The objective is to facilitate an awareness of the impact of talents in sport skill acquisition and assimilate this into our general understanding of expertise. But why are these questions regarding the factors influencing acquisition of expertise important? Because how we acquire expertise affects the development of humankind; it leads to societal change and has learning and psychological implications. Sports offer a domain to test explanations of expertise and this knowledge may then be applied across domains. Society increasingly places significant international importance on sport[1] and people use it to put both talent and expertise into context. Sports popularity has brought about greater resources, which has resulted in better coaching and facilities accelerating the acquisition of expertise. Greater commercial opportunities have caused an aspirational culture to shift from participation as a pastime to employment facilitated by larger incomes.

[1] The TV audience for the 2012 Olympics was 4.8 billion viewers, 68% of the world population.

Sports programs search for talent; these are established as motor-abilities (anthropometric and physiological)[2] and used as a predictor of future performance. However, rarely in sport has this talent included mental abilities, although both theory and empirical research indicates they are influential in attaining expertise (Abd El Shakour, Mohamed Fawzy, 2020; Ackerman, 1988; Deary & Mitchell, 1989; Fitts & Posner, 1967; Paunescu et al., 2013). Therefore, this thesis investigates whether mental abilities predict future performance in sport.

In summary, understanding sports(?) expertise has social, educational, and psychological implications for both global and domain-specific expertise. If an overall theory of explaining expertise is to be developed, then it should include both the influence of talent and practice. This thesis specifically seeks to identify the influence of talent as expertise develops. The sports domain is chosen as the task environment because it involves the enhancement of overt and quantifiable motor actions. It combines both motor abilities and mental abilities, providing the opportunity to identify both physiological and psychological measures and their importance in expertise.

1.2 Purposes and theses.

The motivation underlying this thesis is to broaden the understanding of the contribution from talents to sporting expertise to help contribute towards a general theory of expertise. The objective is to identify talent measures (physiological and psychological) that are prominent across the development of skill acquisition and

[2] British Rowing favours longer limb length, British Cycling favours power output and aerobic capacity.

ascertain their influence on the speed of acquiring expertise. Chapter 2 defines talent and investigates the literature on the measurement and acquisition of motor expertise. Reviewing the talent vs. practice dichotomy, it proposes a researches methodology and a theoretical basis for talent measures. Chapter 3 research how mental abilities affect attaining a sports motor skill; the literature is unclear in this area, although children (van der Fels, I. M. J. et al., 2015) and air traffic controllers (Ackerman, 1988) suggest that there is a link. I associate mental abilities with progression in a hockey task for novice athletes with little hockey knowledge. Chapter 4 and 5 investigates how genetics (Bouchard et al., 1997) influences the speed of expertise. Chapter 4 examines intermediate expertise, where genes affect sports performance (Tucker & Collins, 2012) and the critical periods (Chassy & Gobet, 2010; Tucker & Collins, 2012) in gaining expertise. Contrasting outcomes from two groups of cyclists selected based on one of two talent identification (TID) measures, traditional (race result rank) and detection (measures of power output and cadence) TID. Finally, Chapter 5 identifies the speed of expertise and does the event, or the sport skill influence this figure. Differentiating results between track and field athletes, divided into groups categorized by their performance energy pathway and skill type. Finally, chapter 6 discusses these results suggesting potential applications into theory and practice, considers its limitations and proposes future research.

The purpose of this research is to gather data to test the hypothesis of talent as a significant contributor to motor skill performance and therefore, subsequently expertise. The measurement of this phenomenon is reliant upon the assessment of talent by (a) objective performance measures and (b) the period to excellence (superior performance is analogous to natural abilities).

Therefore, the overriding assumption of this thesis is that talent is significant in attaining motor expertise. This assumption is refined in three hypotheses. First, mental abilities are associated with motor abilities in novices. Second, in TID, athletes selected for training in a sport using physiological markers of potential will have a faster period to excellence than those identified by performance results in the sport. Third, the period to excellence will be dependent upon the energy pathway (aerobic/anaerobic) and skill utilized in performance.

The first hypothesis (chapter 3) was examined by measuring the speed with which novices performance improved when acquiring a new hockey skill and was carried out with undergraduate and post-graduate students *(n* = 40). Performance improvements were related to a range of psychometric tasks that were selected to ascertain multiple psychological phenomena. These include (a) spatial intelligence (Raven's SPM), (b) verbal intelligence (Spot-the-word), (c) working memory (Ospan), (d) perceptual speed (Inspection time), (e) psychomotor ability (Fitts's Law), (f) declarative knowledge and (g) procedural knowledge. Hockey performance was measured using a bespoke design (see Appendix A).

The research for the second and third hypotheses tests the theory that deliberate practice results in the achievement of normative expertise in 10 years (Ericsson et al., 1993). This research posits that if the deliberate practice hypothesis is correct, then achieving expertise in less than 10 years will be the result of a contribution from non-practice factors and as a result will influence the period to excellence. This was investigated using data on Team GB members at the London Olympics 2012, with information of an individuals' period to excellence being obtained from multiple sources (publications, correspondence, and social media).

The second hypothesis was investigated by examining all GB Cycling competitors (Chapter 4). The intermediate stage and progression towards expertise often involves being selected for specialist training using TID. Selection for the Olympic program relies on measures of talent Traditional TID (race results, rankings) or Detection TID measure components of performance (power, anaerobic capacity); thus, in this Chapter, the outcomes for athletes selected based on either methodology was contrasted. This was done specifically to determine if those selected based on physical potential performed better than those with a longer history of taking part in competitive cycling. Finally, the third hypothesis was assessed through analyses of all GB Track and Field competitors (Chapter 5). Individual differences in the energy pathway and skill demands are analysed to ascertain their effect on the speed of expertise.

The discussion chapter 6 presents an overview of results and reflects on points of interest raised by this thesis, such as: Where can talent fit in a theory of expertise? Should the deliberate practice be applied to sport, is the 10,000-hour number that significant, and why did Ericsson et al. (1993) not consider talent effects in their deliberate practice framework? Can we estimate the contribution of talents to performance? I will conclude by discussing the contributions of this thesis to expertise, its limitations, and future directions of research. Thus, I intend to create an argument that defends encompassing innate abilities in the understanding of motor skill development.

2 Chapter 2 Review of Literature.

Consideration of the basis of individual variations in both sporting performance and the ability to acquire sporting expertise inevitably leads to deliberation on the role and nature of talent. Talent is a socially constructed term that offers a universal understanding of differences in task performance (Hay & Macdonald, 2010; Smith, 2001). Theoretical approaches vary in their emphasis on innate or environmental factors according to the researcher's perspective.

- Gardner (1983) defines talent as a sign of precocious bio-psychological potential in a particular domain; it represents component abilities both physical and psychological (Ahmetov & Fedotovskaya, 2012; Tucker & Collins, 2012).
- Ericsson et al. (1993) propose that talent is associated with "unique environmental conditions and parental support" (p. 365).
- Dreyfus et al. (1988) take a holistic approach; they do not define talent but introduce the concept of "beyond rationality" (p. 40), when performance and euphoria peaks, defines as flow. Both flow and creativity leading to expertise and helps flow performance in sport (Carter et al., 2013; Swann, 2016)

The thesis investigates the hypothesis that individual differences in sporting performance are attributable to differing innate abilities, which correspond to talents as defined by Gardner. Specifically, it is hypothesized that superior talent is characterized by greater psychological and physiological resources that can be allocated to skill acquisition and task performance and hence lead to superior outcomes (Ackerman, 1988; Norman & Bobrow, 1975). The available psychological resources can be quantified by psychometric performance in tasks such as working memory capacity, spatial and verbal intelligence, perceptual speed, and psychomotor skills, whilst physiological resources are based on physical measures, such as power output, aerobic capacity, and energy pathway utilization. It is theorized that talent is, at least in part, genetically determined.

This chapter will introduce the key concepts used to examine these claims and also their underlying basis. First, I will outline the way in which acquisition of sports performance will be decomposed into three stages (novice, intermediate and expert). Second, the way that different factors can influence performance are described with reference to the performance-resource function. Third, I outline some of the known genetic influences on performance in this domain, which includes reference to cognitive and mental abilities. Fourth, I consider the influence of non-innate factors affecting expertise. Finally, I introduce the ACT-R model of expertise (Anderson, 1993), which is used as theoretical basis in the thesis for (i) determining the most appropriate areas of mental function that are to be tested (Fitts, 1964; Raven, 2003; Unsworth et al., 2005; Vickers et al., 1972) and (ii) to provide a basis for scoring a motor skill.

2.1 Three phases of motor skill acquisition.

In sports, as with any motor skill, individuals can be characterized with different levels of expertise when performing tasks. The current thesis will catagorise performance according the three broad phases of skill acquisition under the widely used broad headings of novice, intermediate and expert (Ackerman, 1987; Anderson, 1987; Bloom, 1985; Fitts & Posner, 1967; Schneider & Shiffrin, 1977).

- Phase 1, Novice. The novice phase, involves the identification of cognitive functions and is associated with performance (Ackerman, 1987; Bloom, 1985; Fitts & Posner, 1967). When novices attempt a complex task, this involves higher levels of cognitive organization than simple tasks (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Performance is slow and effortful with errors, new strategies are developed and tested, requiring attention to performance and outcomes.
- Phase 2, Intermediate. Bloom (1985) identifies this phase as the middle years and defines the period by a "development of commitment" and sport not being "just a game" (p. 235). Ackerman (1987) determined that progress through this phase was dependent on the nature of the task; a consistent task will lead to automatic processing, and an inconsistent task will require controlled processing.
- Phase 3, Expert. Fast and accurate automatic performance characterizes the expert phase of skill acquisition, which allows the release of spare attentional capacity for other tasks whilst performing the primary task. It is a full-time commitment to retaining and develop expert level performance (Bloom, 1985; Ericsson et al., 1993).

2.2 The Performance-Resource function.

At the heart of the current thesis is the way that sporting performance can be determined by innate factors, which can be considered as resources that can be applied at different levels to a task. However, the relationship between performance in a task and the application of different levels of a particular resource (innate or otherwise) can vary. Figure 1 illustrates many of the potentially different relationships that can occur when increasing the amount of a particular resource devoted to a task (including no relationship, a step function, proportional and a power relationship (Norman & Bobrow, 1975).

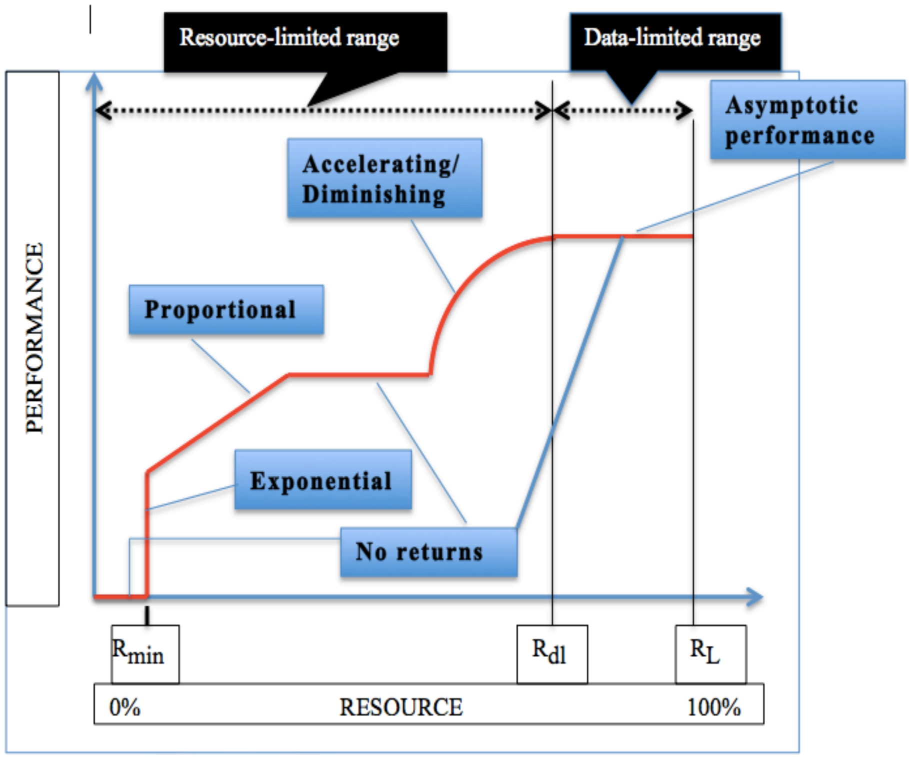


Figure 1. The performance-resource function with emphasis on the potential stages returns on resource investment (Norman & Bobrow, 1975).

2.3 Genetics influence in motor expertise.

Theorists who emphasize the importance of talent in expertise often argue that such participants have a genetic advantage that will materialize in performance. The relationship between genotype and phenotype is a complex one that is partially mediated by the environment (Lehner, 2013; Rutherford, 2000). Nonetheless, relationships established between an individual's physical potential and their genes have frequently been associated with sport performance. For example, muscle mass and strength have been estimated to be between 15% to 90% heritable whilst the heritability of muscle anaerobic power ranges from 46% to 84% (Tucker & Collins, 2012). Also, it is generally accepted that height is predominantly determined by genotype with studies indicating that 80% of its variance can be associated with a complex combination of genes (Lettre, 2009; Weedon & Frayling, 2008).

Therefore, it is expected that athletes who attain world-class performance have a genetic profile that is well suited to the biological, physical, and psychological factors required in their sport. However, understanding these connections is complicated by the links between genetics and performance: (i) most traits are polygenic (i.e., no single gene determines a particular underlying factor); (ii) multiple factors affect performance; and (iii) the contribution of heritability is often below 25% and rarely exceeds 50% (Bouchard et al., 1997). Nonetheless, the links between mental functions and genes may still make a highly significant contribution to variation in individual performance.

A recent meta-analysis of the heritability of human traits based on fifty years of twin studies estimates that heritability is 49% for mental characteristics such as IQ, working memory, perceptual speed, psychomotor skill (Polderman et al., 2015). In particular, the links between heritability and IQ are well researched (Devlin et al., 1997; Savage et al., 2018) with studies showing its important in early childhood (Devlin et al., 1997) and adults (Neisser et al., 1996). Furthermore, working memory and perceptual speed may directly underlie individual differences in IQ performance (Wright et al., 2001) and psychomotor skill may be indirectly affected by its links to perceptual skill difference in performance (Ackerman & Cianciolo, 2000).

Memory contributes to intellectual ability, and it contributes to skill acquisition through two constructs, memory span (short-term storage limits) and working memory (ability to process information in short-term storage) (Baddeley, 1992). Working memory improves counting, operation tasks and reading tasks. “These tasks measure the ability of individuals to keep task-relevant information in a state of task heightened activity during the execution of a processing task” (Furley & Memmert, 2010, p. 175). Research on span memory and intelligence (Spearman’s g) indicated a large significant relationship (Beier & Ackerman, 2004). Importantly, working memory has been linked to novice skill acquisition for visuomotor adaptions and motor sequence learning (Anguera et al., 2010; Bo et al., 2009). Also, according to the controlled attentional theory, working memory span can predict cognitive behaviour such as reading and comprehension (Daneman & Carpenter, 1980; Daneman & Carpenter, 1983). Individual differences in spatial working memory predict the speed of motor learning in a laboratory experiment, specifically the ability to chunk action elements together in working memory to facilitate subsequent new actions (Seidler et al., 2012).

Therefore, performance in both motor and mental abilities have been linked to genes, Researchers have proposed links between the acquisition of expertise and genetically determined cognitive processes. The “expertise specific optimal pattern” (ESOP) hypothesis is concerned with how short- and long-term memory affects the speed of expertise development. It states “that some individuals have a pattern of alleles that allows the best cooperation between the various mechanisms entering the equation of memory storage” (Chassy & Gobet, 2010, p. 22). ESOP suggests the involvement of different genes from one domain of expertise to another. For example, chess and piano playing requires the chunking of different types of information for task enhancement, e.g., visual pattern encoding compared with visual-motor association. The ability to learn is proportionally related to the biological facility to encode the required information.

2.4 The contribution of non-innate factors to expertise.

Nonetheless, the majority of research in sport has examined and emphasized non-innate factors that contribute to changes in performance.

2.4.1 Practice.

Probably the most studied factor in sports performance improvement is practice (Daniels & Scardina, 1984; Falk Neto & Kennedy, 2019; Littlewood, 1964; Viteles, 1933; Wildman et al., 2010). Research on practice proposes the role of simple repetition in obtaining expertise and that there is a power law between practice and performance. Researchers emphasizing the contribution of practice tend to be split on the fundamental requirements of the nature of practice: either (a) power gains of practice follow similar power functions, which depend upon *general features* of the learning situation or a learning system (Newell & Rosenbloom, 1981); or (b) deliberate practice hypothesis (Ericsson et al., 1993), which states that, to acquire expertise, practice should be deliberate, motivated, and *domain-specific*.

The power law of practice indicates that greater levels of training will result in better performance but does not include other factors like the training period, coaching and other combinations that can influence outcomes (Rees et al., 2016). In contrast, the theory of deliberate practice that has been extensively researched in sport emphasizes factors that affect the training environment (Baker et al., 2005; Ford et al., 2015; Helsen et al., 1998; Helsen et al., 2000; Hyllegard et al., 2002; Hyllegard & Yamamoto, 2007; Lombardo & Deaner, 2014; Staff et al., 2021; Young & Salmela, 2002). It hypothesizes that the attainment of expertise occurs by sustained investment in domain specific activities explicitly designed to improve performance in the domain of desired expertise (Ericsson et al., 1993). Ericsson et al. also emphasize that deliberate practice is not inherently motivating or enjoyable and therefore can only be sustained for limited periods to prevent fatigue. It is individual-focused, requires teachers, training material and facilities, and progression occurs with practice, not competition. The acquisition of expertise is a gradual monotonic increase over time and is optimal following early specialization of practice in the chosen domain.

Ericsson et al.'s (1993) influential prediction of the deliberate practice framework is that "… expert performance is not reached with less than 10 years of deliberate practice" (p. 372). Based on Simon and Chase's (1973) estimate of 10,000 hours, this period to excellence of 10 years (or 10,000 hours) is a minimum that applies across all domains. Thus, the deliberate practice framework considers the period of expert attainment in mathematics, sport, and teaching to be the same, given appropriate levels of deliberate practice.

Individual differences in capability (talent) are not part of this theory. Ericsson et al. (1993) suggests that the tenet of talent has developed due to weak hypotheses advanced to explain expertise. Talent as an indicator of future performance is dismissed and they claim, "we deny that these differences are immutable, that is, due to innate talent" (p. 400). They hypothesize that the best individuals practice more than inferior performers, and also ascribe early superior performance across individuals to factors associated with practice motivation (i.e., initial skill, personality, and parental influence; see complementary traits in the next section).

2.4.2 Complementary traits that influence performance.

Complementary traits are factors that may bring about performance differences but are considered by some theorists to arise from current and past environmental factors rather than talent. Factors that have been identified in this category include (i) personality (Ackerman & Heggestad, 1997), (ii) motivational influences (Kanfer & Ackerman, 1989), (iii) prior knowledge transfer (Sullivan, 1964), and finally (iv) other determinants.

Personality.

There is dispute amongst researchers as to the degree to which personality factors are determined through social learning (Bandura & Walters, 1977) or genetics (Penke et al., 2007). Personality can affect sport interest (Wolff et al., 2021) and provide multiple outcomes (i.e., extravert tendency and drive) (Eysenck et al., 1982). Indeed, it has been argued to be a determinant of whether individuals participate in sport and may underlie long-term success (Allen et al., 2013).

Motivation.

It is generally believed that higher motivation may underlie differences in individual performance (Vroom, 1964). The genetic effect on sports participation through physical activity and resting metabolic rates affects low to moderately high motivation effects (Beunen & Thomis, 1999). However, this relationship interacts with task difficulty. For easy tasks, motivation is a good predictor of performance, but ability is a poor predictor. Whilst with complex tasks, it is the combination of both ability and motivation that influences performance (Terborg, 1977).

Prior knowledge transfer.

Performance of a task involves two types of skills: (i) task-specific skills, which do not transfer to other tasks, and (ii) transfer skills that are common across other tasks. Transfer skills have been found to be a very important determinant of performance when adopting a new sport (DiFiori et al., 2017; Güllich, 2018; Rees et al., 2016).

Other determinants.

The influences of unaffiliated measures such as self-concept, vocational interests, and self-efficacy were investigated to ascertain their relationship in complex task performance following a practice. Self-concept is the ability to judge one's performance competencies; vocational interests are representations of motivation. Self-efficacy is confidence in the ability to succeed in a task. Results showed that these measures are correlated with improved performance. When there are no direct ability measures, it is possible to use these determinants (Ackerman et al., 1995).

2.5 Applying ACT-R to sport skill acquisition.

In examining factors affecting sports acquisition, it is important to take a theoretical approach to determining (i) which factors may affect skill acquisition, and (ii) how best to measure changes in sports performance by identifying the component processes of learning. The current thesis has applied the ACT-R cognitive architecture to address these issues. ACT-R (Anderson, 1996) models information processing from a human perspective; it is a theoretical explanation of the mental processes and individual differences in play when obtaining expertise. It comprises of a set of independent modules encoding symbolic information in three processing areas: perceptual (visual, aural), central processing (procedural, declarative, goal, imaginal), and response (manual, vocal) (see figure 2). These modules can be evaluated in serially or in parallel productions, each assess the best possible outcome for the current goal.

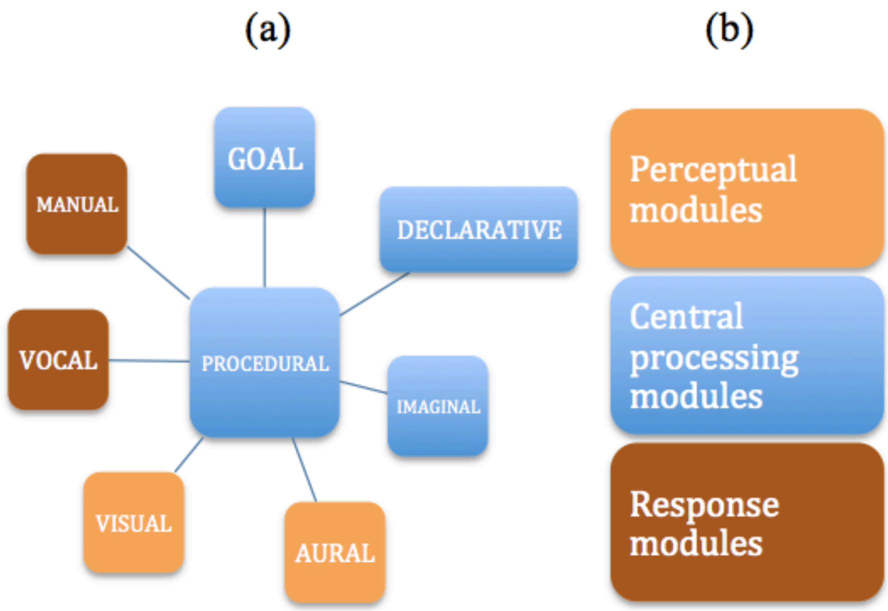


Figure 2. Symbolic module implemented in ACT-R modified from (Anderson, 2007).

A brief explanation of each module now follows:

a) The Visual module identifies objects in the visual field and the aural module identifies objects in the auditory field.

b) The manual module is responsible for controlling and monitoring movement and the vocal module both generates verbal responses and controls internal sub-vocalising.

c) The Goal, Imaginal, Declarative and Procedural modules instantiate central processing control.

i. The Goal module continually assesses current progress in the problem-solving process (i.e., analysing partial results within the context of the outcome).

ii. The Imaginal module assesses the problem, and a solution is proffered; a mental representation that is retained cognitively before any action.

iii. The Declarative module retrieves, selects, and holds task critical factual information from long term and working memory. Information is stored in chunks with new chunks developed by adding to existing knowledge (Miller, 1956).

iv. The Procedural module comprises learned behavioural rules (known as productions) and embodies cognitive processing. These rules consist of two parts, a condition (IF) and a resulting action (THEN), whose objective is to evaluate the current module states trigger actions that achieve the current goal.

Thus, ACT-r consists of templates, building blocks for cognitive representations; it includes multi-module interactions that determine overall performance. Taatgen, Lebiere and Anderson (2006) compare the modular components of ACT-R to "program agents that exhibit human-like behaviour" (p. 32). ACT-R offers a modular analysis of the mind at both a functional (mental) and structural (neural) level. Its hypotheses separate processing stages, including perceptual, central processing and response modules, to breakdown psychomotor performance. In the behavioural sports skill acquisition literature, many tasks can be decomposed into the same processing steps. For example, in a ball skill requiring sensory input, decision process, and action modules follows the same processing steps as ACT-R (Whiting, 1969). Indeed, it offers a more structured analyses of information processing, break down motor performance in which mental abilities contributed. I have selected working memory, perceptual speed, psychomotor skill, and intelligence, plus measures of declarative and perceptual knowledge to represent these abilities.

Empirically, learning is achieved through task interpretation, activating analogous rules (if a specific one does not exist), trial performance, acquiring knowledge, and improving performance on subsequent occasions.

2.6 Summary and Preview of Thesis.

This chapter has considered theories underpinning the definition of talent in sport. It has identified three stages in the acquisition of expertise and sought to understand how the role of talent changes with time. It has discussed how talent can affect sports performance.

The study of this thesis addresses the importance of talent in obtaining expertise. The first study investigates the role of mental abilities in a novel sports-based motor skill. The study hypothesizes that participants with greater mental processing abilities will more quickly attain a motor skill. The second study investigates talent as precursor to excellent physiological performance. At the intermediate stage, established talent identification measures of micro physiology (power output) are utilized to determine how they affect the speed of motor acquisition. Finally, the third study investigates how physiological demands of the sport (anaerobic, aerobic energy system) influence the speed of motor acquisition.

3 Chapter 3. Novice phase – cognitive potential.

3.1 Introduction.

There is a consensus that expertise is multifaceted (Ackerman, 2014; Dreyfus et al., 1988; Gobet, 2015; Wai, 2014). In the sports domain, experts require "extraordinary physiological capacities combined with outstanding abilities in areas such as motor control, perception and cognitive functioning" (Scharfen & Memmert, 2019, p. 1). Therefore, it is possible to speculate that superior sporting performance is associated with higher mental abilities (Scharfen & Memmert, 2019; Voss et al., 2010). The comparison of cognitive abilities in sports groups has found support for this hypothesis across a range of sports, e.g., in expert and novice footballers (Verburgh et al., 2014; Verburgh et al., 2016; Vestberg et al., 2017), recreational, elite youth and adult table tennis players (Zhang, 1994), point guards in basketball (Yang & Fu, 1998) and across sports such as basketball, handball, baseball, gymnastics and archery (Zhu & Fang, 1988). However, there is little research that examines whether higher mental abilities are a precursor to expert performance and how they contribute towards skill acquisition.

In assessing potential future performance, talent identification (TID) is generally based on the outcomes of practice (Vaeyens et al., 2009; Williams & Reilly, 2000; Williams & Ford, 2009). Talent identification in sport has largely ignored mental abilities, defined as psychological components employed in gathering, organizing, holding, and combining knowledge to determine actions (Gardner, 1983). These factors may be advantageous in developing sport expertise, and their importance is evidenced by theories of learning from researchers outside this field (Ackerman, 1987; Ackerman, 2014; Bloom, 1985; Fitts & Posner, 1967; Shiffrin & Schneider, 1977).

Given the importance of talent identification in the development of sports performers and the prominence of psychometric performance in talent selection processes such as school entrance, job recruitment and pilot selection (Becker et al., 2012; Beech & Harding, 1990; Hunter & Burke, 1994; Lievens & Patterson, 2011; Martinussen, 1996), mental abilities have surprisingly not been studied in sports talent identification methodologies as a potential precursor to future motor performance. However, limited research exists into this relationship, mainly from studies in China (Junwu, 2012; Wu et al., 2019) and the work of a few investigators from outside the UK, for example studying the role of intelligence in Taekwondo performance (Paunescu et al., 2013) and psychomotor ability in tennis (Abd El Shakour, 2020)

These mental abilities can be assessed by several psychometric measures of working memory capacity (WMC), intelligence, perceptual speed, and psychomotor ability. Working memory capacity (the ability to retain and manipulate small amounts of information in mind while performing a complex task) interacts with long-term memory and is constantly reconfigured when performing tasks (Baddeley, 2010). Research indicates it is associated with learning a simple sports-related skill (Buszard et al., 2017). Assessment of WMC is commonly based upon span measures such as counting, operation and reading tasks. “These tasks measure the ability of individuals to keep task-relevant information in a state of task heightened activity during the execution of a processing task” (Furley & Memmert, 2010, p. 175). Individual differences in spatial working memory predicted the speed of motor learning in laboratory experiments, specifically the ability to chunk action elements together in working memory to facilitate subsequent new actions (Seidler et al., 2012).

Furthermore, working memory capacity predicts cognitive behaviours such as reading comprehension (Daneman & Carpenter, 1980; Daneman & Carpenter, 1983; Johann et al., 2020), and it is influential in novice skill acquisition for visuomotor adaptions and motor sequence learning (Anguera et al., 2010; Bo et al., 2009).

Intelligence is a broad construct thought to underlie consistency in differences between individuals across a range of cognitive abilities (Plomin & Deary, 2015). The assumption is that the individuals' variance on such tests is mostly attributable to non-specific information processing capabilities. It is not task or content-type specific, i.e., applicable to only verbal and numerical content, and is defined as "resultant of the processes acquiring, storing in memory, retrieving, combining, comparing and using in new contexts information and conceptual skills" (Humphreys, 1979, p. 115). In this view, intelligence consists of a whole group of specific abilities categorized as fluid and crystalized factors (Horn, 1965). Research associating intelligence scores and sports performance has often utilized the Wechsler Adult Inventory Scale (WAIS) (Wechsler, 1981). Results indicate a broad range of findings in expert athletes: (a) superior sports abilities are associated with better IQ (Li & Xiong, 1993); (b) the performance IQ correlation diminishes as experts become more competent (Ge, 1997) and (c) those participants in a sport where higher-level movement abilities are required (gymnastics, basketball decathlon) have a higher IQ than participants in other sports (Zhu & Fang, 1988).

Perceptual speed is defined as the ability to compare patterns or configurations that involve a degree of similarity or identity (Fleishman & Quaintance, 1984). A high perceptual speed is a good predictor of individuals' perceptual-motor task performance, as those with higher perceptual speed can process information quicker and more efficiently. Psychomotor ability concerns speed and accuracy of stimulus induced reaction times, which is largely free of information processing costs (Fitts, 1964). Individual differences are measured by testing speed response using tasks with minimal or no cognitive demands (Ackerman, 1988).

Beyond those mental abilities, the current state of an individuals' knowledge can be used to estimate the level of expertise of an individual (Gobet, 2015). Knowledge can be split into two main classes: declarative and procedural knowledge (Anderson, 1993). Declarative knowledge consists of facts; procedural knowledge is how to perform a specific skill or task and can be modelled as a set of rules that select the actions that best suit the current conditions (Anderson, 2007). Given that the Adaptive Control of Thought - Rational (ACT-R; Anderson, 2007) theory is based on these two types of knowledge, it is possible to utilise it to score the development of a motor task.

ACT-R incorporates perceptual and central processing as well as clear definitions of how to determine the knowledge currently used by the response modules. Therefore, our mental abilities and current skill measures can be identified within the task performance. Consequently, if an IF-THEN rule satisfies a task, a condition is identified, and the action takes place.

Ackerman (1987; 1988) proposed that the nature of the association between mental ability and motor ability (MAMA) depends upon the period of development and the complexity of the task. He proposed a three-phase model, in line with other researchers (Anderson, 1987; Bloom, 1985; Fitts & Posner, 1967; Shiffrin & Schneider, 1977), where each phase is associated with differing mental abilities. At phase 1 (the novice period), intelligence predicts consistent differences between individuals; however, the high initial demands that performance makes on intelligence attenuates with increased proficiency. At phase 2 (the intermediate period), a high level of perceptual speed is a good predictor of individuals' perceptual-motor task performance (Deary & Mitchell, 1989; Wu et al., 2019) and their ability to process information quickly and efficiently (Werdelin & Stjernberg, 1969). Finally, at phase 3 (the expert period), the correlation between performance and psychomotor abilities increases (Ackerman, 1988). Schneider and Shiffrin (1977) hypothesized the development of task expertise results in information processing changing from controlled to automatic processing as the task evolves from being inconsistent to consistent. Ackerman (1984) suggested that an inconsistent task would be more beneficial in discovering the influence of mental abilities than a consistent task.

There is a paucity of research associating MAMA relations in sports, and in recent investigations, the focus has been on competitors that have achieved high levels of expertise (Hunter & Burke, 1994; Junwu, 2012). Research into individual differences associating mental abilities with the potential for developing sports expertise is minimal. There has been no consideration of its potential applicability in TID. Mental abilities have been associated with performance in studies of children' development (Davis et al., 2010; Davis et al., 2011), research that partially underpins the current study. The review is now divided into adult and child participants, as results demonstrate a different pattern of results.

3.2 The influence of mental abilities on motor skill acquisition in children and adults.

A considerable amount of theoretically grounded work has been conducted in the child development literature to understand the relationship between physical and mental development using motor tests like Strel, Körperkoordinationstest für Kinder, KTK, MABC and Maastricht Motor Test (Barnett et al., 2007; Krombholz, 1997;

Streiner & Norman, 1995; Strel, 1996). This developmental period is analogous to phase 1, the novice period, of sports skill acquisition which starts from low levels of declarative and procedural knowledge. Indeed, the Strel test has been associated with goalkeeper saves in children playing handball (Krawczyk et al., 2019)

Krombholz (1997) used a body coordination test for children (Körperkoordinationstest für Kinder, KTK) and found a significant positive relationship ($r = .53$) between physical and cognitive performance in both kindergarten and elementary school children. Similarly, Planinsec (2002a; 2002b) found strong positive significant correlations between mental abilities and performance on the Strel motor tests (Strel, 1996). In Planinsec (2002a), the correlation between fluid intelligence and performance in 10–14-year-olds was ($r = .49$, $p < .05$); in Planinsec (2002b), the correlation between cognitive tests and performance in 5-6-year-olds was ($r = .51$, $p < .01$). Furthermore, Planinsec and Pisot (2006) reported a performance difference in the Strel tests between high and low intelligence groups of 13-year-olds.

Likewise, in assessing IQ and motor scores, Smits-Engelsman and Hill (2012), who utilized the MABC test (Barnett et al., 2007), reported a significant correlation of $r = .44$ ($p < .01$) in 4-13-year-olds. Finally, Wassenberg et al. (2005), using the Maastricht Motor Test (Streiner & Norman, 1995), reported that, although there were no consistent relations between cognitive and motor performance, performance requiring executive functioning such as attention is related to motor performance in 5-6-year-olds.

Furthermore, in a recent meta-analysis, van Der Fels et al. (2015) indicated that the MAMA association was stronger in pre-pubescent (< 13 years) but still evident in pubescent children (≥ 13 years). They concluded that mental abilities were significantly associated with three underlying categories (fine motor skills, bilateral body control and timed performance in movement) but not with gross motor skills, object control and total motor score.

However, the well-established relationship between mental and motor abilities in children has had little impact upon research on adults learning a sports skill where early skill acquisition starts from low amounts of declarative and procedural knowledge. To my knowledge, Paunescu et al. (2013) is currently the only research that specifically identified the importance of cognitive levels in untrained, adult-novice participants performing a sports skill. They studied 40 participants (18-21 years) randomly selected from 100 physical education and sports candidates and reported a strong positive relationship between general intelligence (Raven's SPM) (Raven, 2003) and motor skills in learning Taekwondo. The Taekwondo ability assessment consisted of three basic techniques that were taught from a theoretical and practical perspective using demonstrations. Participants' task performance was assessed on a three-point scale in three areas: (a) mentally performing the skill, (b) reproducing the skill at a reduced speed and (c) performing the skill at performance speed. Results indicated a strong positive correlation between intelligence and Taekwondo performance scores ($r = .76$, $p < .001$). The authors suggested that performance gains and the strength of MAMA relations were due to task understanding rather than the demonstrations used during the teaching process.

3.2.1 The Present Study.

This research investigates the relationship between mental abilities and motor task performance using a complex hockey skill in novices. The hypothesis is that, in learning to perform a hockey task, those with higher scores on tests of mental abilities will improve in performance faster than those with lower scores.

Evaluating the literature on the association between mental abilities and motor performance in sport suggests that a *top-down* approach is employed, whereby exceptionable is analysed and replicated in novice training regimes. The focus is on "what experts do." This contrast with a *bottom-up* approach where superior mental abilities are a forerunner to expertise. In general, researchers have bypassed the influence of mental abilities and how they affect sports skill acquisition.

Psychometric measures have been used in previous MAMA studies in the sports domain utilised: working memory (Verburgh et al., 2014; Verburgh et al., 2016), intelligence (Junwu, 2012; Paunescu et al., 2013), perceptual speed (Deary & Mitchell, 1989) and psychomotor ability (Abd El Shakour, 2020; Wu et al., 2019). The hockey task is measured using a theory of cognitive mechanism, ACT-R to understand the performance that takes place. In additional, inspection of the developmental literature guided the current methodology and its framework, so that measures are theoretically grounded.

3.3 Methodology.

3.3.1 Participants.

Forty participants (3 males and 37 females), 33 of whom were right-handed, were recruited from the participant pool of the psychology department at Brunel University London. Participants with prior hockey skills or knowledge were not selected. The average age was 20.04 years (*SD* = 2.78 yrs). All undergraduates received course credits, and the top three performers received an Amazon gift card for the best three performances (£50 for the 1st, £35 for the 2nd and £25 for the 3rd).

This study was carried out following the recommendations of Brunel University London, psychology department and conducted under the ethical standards of the Declaration of Helsinki. Written, informed consent was obtained from each participant. The expert portrayed in figure 7 and utilized as the video coach gave permission to publish this material.

3.3.2 Procedure and Materials.

Testing consisted of two consecutive testing sessions separated by a comfort break. Each session was in different locations due to the requirements of the hockey task. Over the two sessions, each participant individually completed (a) the hockey task and (b) seven psychometric tests, with the researcher available throughout each session. In the first session, the researcher provided an overview of the experimental procedure and participants signed a consent form and provided demographic information. They then completed declarative and procedural knowledge questionnaires, followed by the hockey task. After a short break, they completed the Raven's progressive matrices and the Spot-the-word tasks. To conclude session 1, they indicated their levels of motivation, irritation, and interest in these tasks. After a comfort break, the second session continued in a different location consisting of three computerized psychometric tests: (a) Fitts's task; (b) OSpan working memory task and (c) Inspection Time task. The session finished with the participants indicating their levels of motivation, irritation, and interest in these tasks.

3.3.3 Mental ability tests.

Working Memory Assessment.

Working memory capacity (Baddeley, 2010) was measured using the automated Operating span, OSpan (Beaman, 2004; Laubacher, 2020; Unsworth et al., 2005). Words were presented in groups of two to five items; the set order changes randomly so the set is not repeated, and participants were instructed to recall the words. Participants answered mathematical questions (whether equations are correct or not) while memorizing each group of words. An 85% success rate for the math problems was required to ensure that participants were not trading off mathematical accuracy to remember the order of words. Scores consisted of the total number of correct words in the correct order.

Spatial Intelligence.

The Raven's standard progressive matrices are a spatial and reasoning intelligence test (Lorås et al., 2020; Raven, 2003; Ullén et al., 2016). It consists of sixty items presented in five groups. Within each group, the number of multiple-choice options increases, and the problems become increasingly more complex. Each item consists of a matrix of geometric patterns with the bottom right section missing. The task is to select the correct item from a choice of between six to eight options to complete the matrix. Training consists of two practice problems, and a participant's score is the total number of correct answers.

Verbal Intelligence.

The Spot-the-Word test measures verbal intelligence (Baddeley et al., 1993; Gregory et al., 2010; Leahey et al., 2020). This is a pencil and paper test consisting of sixty pairs of items; in each pair, one item is a real word, and the other is a nonsense sequence of letters invented to look like a word but having no meaning. Pair examples are “kitchen and *harrick*”, and “puma and *laptess*”. The objective is to select the real word. A participant’s score is the total number of correct answers. Task training consists of two problems.

Perceptual speed.

Inspection time (IT) is an evaluation of perceptual recognition speed and is a psychophysical measure based on Vickers’s visual perception model (Lambourne & Tomporowski, 2010; Payne & Smith, 2014; Vickers et al., 1972; Vickers & Smith, 1986). It is a simple discrimination task in which, following a “+” fixation sign, participants judge whether a rapidly presented and backward masked stimulus had a (a) longer leg on the left, and (b) longer leg on the right (see Figure 3). Response is via a keyboard by selecting 1-2.

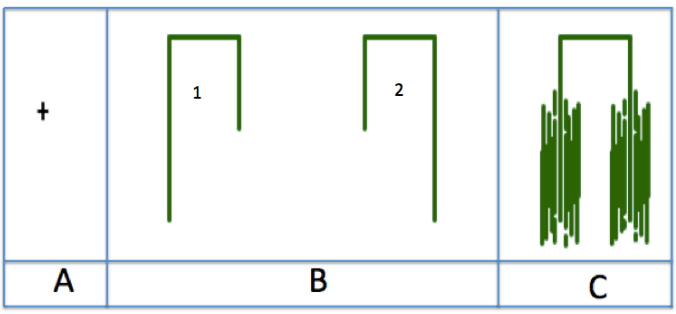


Figure 3. Inspection time task: A. fixation cross; B. stimuli used (only one stimulus is presented at a time); and C. backward mask.

The stimuli were displayed at eight presentation times (10, 22, 33, 45, 56, 80, or 92 msec), followed immediately by the backward mask. These durations were determined following piloting to cover a range of presentation times where participants would range from 100% success and 50% chance success. Testing consists of one block of ten trials with feedback on accuracy followed by eight blocks of twenty with no feedback. Only the correct trials contribute to the final score, and these results were fitted to a psychometric function (see figure 4). An individual's inspection time threshold was taken as 75% accuracy on the psychometric function.

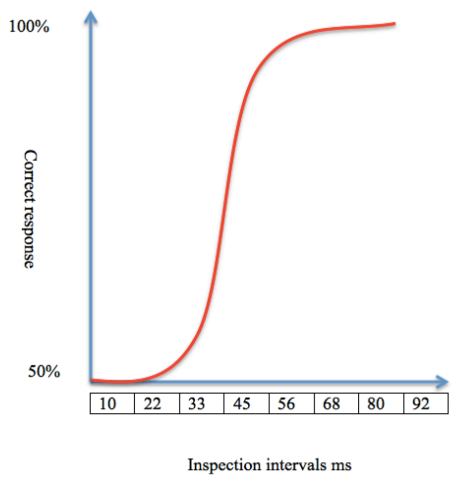


Figure 4. Example of a psychometric function, displaying correct response probability as a function of inspection intervals.

Psychomotor ability.

Fitts's Law (Aloraini et al., 2020; Fitts, 1954; Hill, 2014) measures psychomotor performance, the interaction between mental activity and bodily movement (Coleman, 2015). In the current implementation, participants' task consists of tapping the centre of a target green strip on a touch screen (Wacom Cintiq 22); the green strip changes in width (4.5, 6, 9, 12 mm) and location, and alternates between left and right (see figure 4). The task is programmed in E-Prime (Schneider et al., 2012) and run on a Windows PC. Each trial consisted of 80 selections where the target strip is connected are measured. Three parameters are recorded, (a) time of movement to target (MT), i.e., the time between selection of green target on the first screen and the second screen, (b) the distance between the starting point and the target centre (w_adj) and (c) the target width (W). Calculations consist of an index of difficulty (ID) = LOG (2* (w_adj)/W, 2) and an index of performance (IP) = ID/MT. The change in performance (IP) as difficulty (ID) varies (see figure 5) represents an individual's abilities. It is the slope that represents an individual's psychomotor abilities, with smaller slopes indicating better performance.

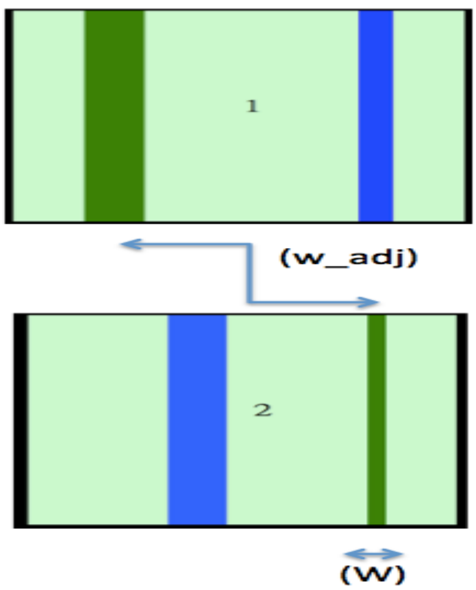


Figure 5. Example of consecutive screens 1 and 2 during the Fitts's Law task.

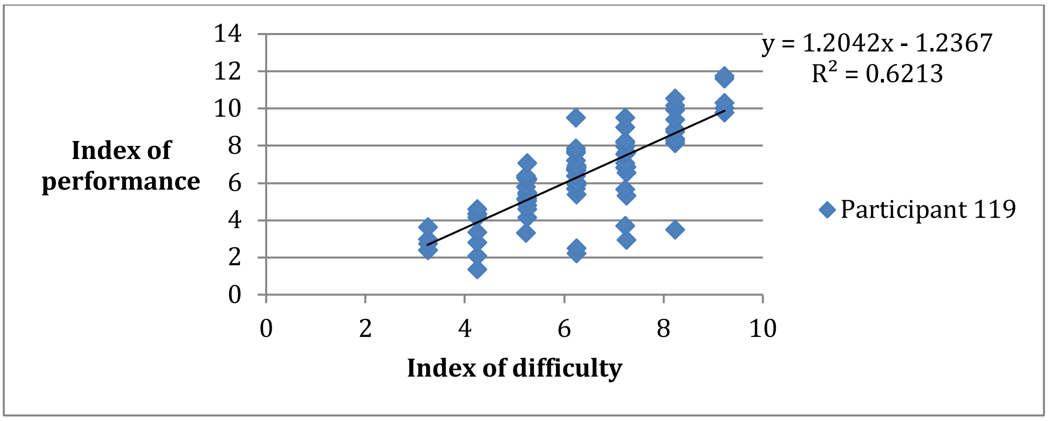


Figure 6. Fitts's Law. Example of calculating a participant's psychomotor performance.

Declarative and Procedural Knowledge.

The scores for declarative and procedural knowledge were measured by bespoke questionnaires that required each participant to self-rate their declarative knowledge and perceived skill (procedural knowledge) in a range of ball sports using a Likert scale ranging from 1 (very low), 2 (low), 3 (moderate), 4 (high) and 5 (very high) (see *Appendix B)*. The ball sports selected were field hockey, hurling, cricket, tennis, lacrosse, football, netball, basketball, roller hockey and ice hockey. These questionnaires provided an initial measure of hockey task declarative and procedural knowledge before testing commenced.

Task motivations, irritation, and interest.

Operationally, motivation is defined as the direction and intensity of effort (Sage, 1977). Motivational theory suggests state anxiety levels reduce a participant's intrinsic motivation. Achievement motivation represents the enthusiasm applied to a task, with higher amounts resulting in better performance (McClelland et al., 1953). In the current study, tasks were completed in two sessions (see *appendices* C and D for each questionnaire). At the end of each session, participants indicated their current levels of motivation, irritation, and interest by answering the following questions: (a) How motivated are you? (b) How irritated are you? And (c) How interested in the task are you? This was self-scored using a Likert scale, consisting of 1 (very low), 2 (low), 3 (moderate), 4 (high) and 5 (very high).

3.3.4 Motor Ability Task.

Hockey task.

The hockey task was recorded on video, utilizing a hockey stick and ball, a training hurdle, and a training spot as the target, as shown in figure 7. The starting point "X" for the ball was not fixed but was dependent upon the participant's selected position. The time allocated for this task was ten minutes, and the number of trials was participant dependent, not predetermined in advance. Measuring performance at fixed points made comparisons between participants possible (see table 1).

The task was described to the participants as follows: "the objective is to lift the ball over the hurdle using the hockey stick and control the ball on the spot." Following the initial task explanation there was no further researcher input, only task clarification.

Table 1. Defining fixed trials.

T1	The first trial, pre-video. This is the first performance time. It is the individual starting point of their basic ability.
T2	The fifth trial, pre-video. The performance time after 5 trials; represents the basic ability to improve with knowledge of results but not coaching.
T3	The first trial, post video. The performance directly after the first video intervention. The initial interpretation of what need to be done to enhance performance.
T4	Mid trial between T3 and T5, post-video.
T5	The last trial post video. The final performance after multiple video interventions.

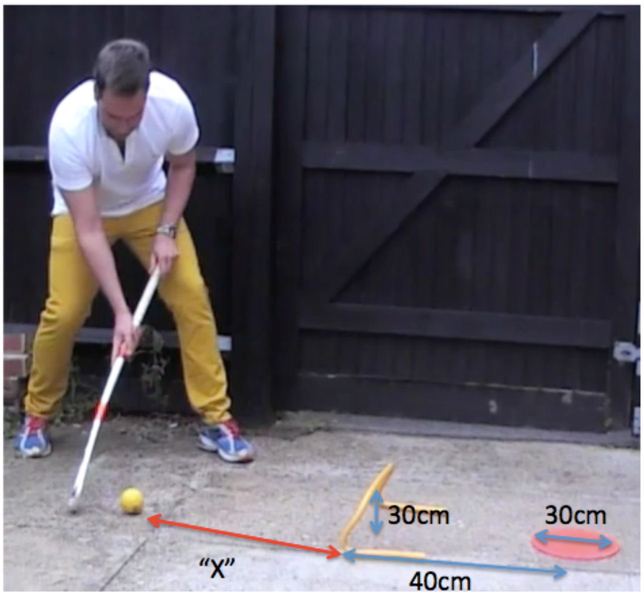


Figure 7. Set up dimensions of the Hockey task.

Intervention.

Participants completed five trials and could then access a 5-second video in which an expert is performing the skill. A video of an expert performing the task maximizes processing effort and cognitive load. The video was available to assist performance from trial six until the end of the session. There was no limit to the amount of time practicing or to the time spent interrogating the video. The number of trials performed during the 10 minutes was dependent upon each participant; the minimum requested attempts were six trials, and there was no maximum number.

Hockey performance measures.

Two scoring systems were designed based on traditional Hockey coaching methods (Gendron & Stenlund, 2003; Mitchell-Taverner, 2005; Wein, 1973). (a) *Positional*, which assessed body adjustments concerning stick and ball, e.g., correct hand position (top left hand, bottom right) and (b) *Technical*, changes in biomechanical and kinematic measures, e.g., the starting distance of the ball from the hurdle. See *Appendix A* for the scoring chart. The results were obtained using both methods and performance changes using both methods were correlated with the time and each other. Both methods were highly sensitive to changes over time and highly correlated with each other (suggesting they tapped into similar factors). The method yielding the slightly higher correlation with time was selected for use throughout the chapter (though either would produce almost identical results).

The hockey task yielded an overall score from three component stages (Preparation, Throw, Control). Performance is measured by a collection of IF-THEN rules: condition and action; thus, when a condition is satisfied, a rule is identified, and the action takes place. To determine the score, ACT-R theory (Anderson, 2007) selects symbolic information in three processing areas, perceptual, central processing, and response. The response area identified manual performance results (see Appendix A) of score 5 for correct technique applied or 0 for unlikely to process any further with the application of this technique. Thus, the spacing between these scores recognised the action between the extremes, indicating if good or poor decisions are acted upon.

The perceptual and central processing information explains how much visual information is received and the outcome. Scores are 3, progress towards the correct technique application but not fully achieved and score 2, a solution based rather than technically correct attempt. Identifying if the athlete will go further or be restricted, the central processing (procedural, declarative, goal, imaginal) leads towards bette3r or worse performance.

Coding of the hockey task.

As shown in table 1, five fixed comparison points identified participants performance. These are

1) Pre-video intervention Trial 1.
2) Trial 5.
3) Post--video intervention at trial 6.
4) Calculated at the midpoint between trial 6 and the last trial.
5) The last trial.

The following notation was used: Preparation (P), Throw (T), Control (C) and Overall (O). Therefore, it follows that P1 = Preparation score at trial 1, T1 = Throw score at trial 1, C1 = Control score at trial 1. The Overall score at trial 1 follows the formula O1 = P1 + T1 + C1, and the other fixed comparison points are numbered accordingly from 2 to 5.

3.4 Data analysis.

3.4.1 Hockey Task.

The scoring chart identifies the progression of each subcomponent on either scoring methodology (positional, technical). The biomechanical program Dartfish (Eltoukhy et al., 2012) facilitated video analyses and subcomponent scoring. The five fixed points utilized to compare the subcomponent range of scores against actual performance were identified in the video, and then a score was allocated. This process was repeated for all five comparison points, and a range of performance scores was calculated. The preparation stage went from P1 to P5 inclusive, the throw stage from T1 to T5, the controls stage from C1 to C5, and the overall stage from O1 to O5. The measurement of performance focused on two performance dimensions: (a) *positional scores*, which calculated body adjustments concerning stick and ball, and (b) *technical scores*, which were based on biomechanical and kinematic adjustments.

3.4.2 Statistical Analysis.

Data analysis used the IBM SPSS Statistics package 26.0.0. Students with hockey knowledge were not included in the final sample, resulting in skewed measures of declarative and procedural knowledge. Pearson's correlations were used to investigate the bivariate correlations between mental and motor abilities. An entry method multiple linear regression analysis was used to investigate how combined mental abilities predicts performance, adjusted R^2 was used to calculate a Cohen's f^2 effect size. Following convention, an r of 0.10, 0.30, and 0.50 represent small, medium, and large effect size estimates, respectively (Cohen, 2013). Removal of outliers followed the method suggested by Tukey (1977) based on a mean quartile (Q1 to Q3) method; upper Q3 + (1.5 * (Q3-Q1)) and lower Q1- (1.5 * (Q3-Q1) (Hoaglin et al., 1986; Hoaglin & Iglewicz, 1987).

3.5 Results.

3.5.1 Hockey score.

Hockey performance was measured using two methodologies, positional and technical. The overall (O) scores for each measure, calculated at five fixed points across the task duration, are displayed in figure 8, which clearly shows a very similar trajectory of mean overall performance for the two measures. This was further confirmed by a Pearson correlation between these two sets of scores ($r = .99$, $p = .001$). To select the score used to later represent mean overall performance over time, correlations were computed with time: positional ($r = .945$, $p = .016$) and technical mean performance ($r = .902$, $p = .036$). The stronger association was with the positional measure, which thus was selected over the technical one.

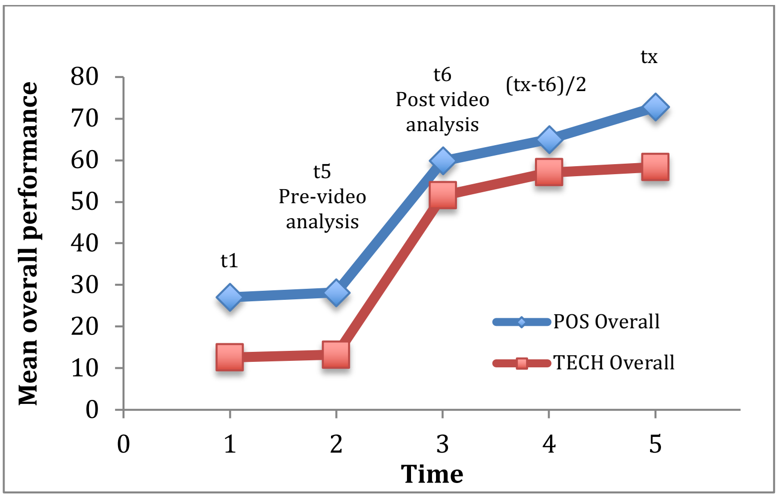


Figure 8. A marked line comparison of positional and technical performance measures; mean overall scores across five comparison points.

3.5.2 Descriptive statistics.

Hockey task, Overall performance.

The overall performance score was divided into three stages: preparation, control, and throw (see figure 12). A one-way repeated measures ANOVA was conducted to compare the effect of time and O scores with particular emphasis on changes following the introduction of the video coach. There was a significant effect of time (1 to 5) on O scores $F(4, 195) = 19.68$, $p < .001$, $\eta_p^2 = .29$. Post hoc comparisons using Tukey HSD test revealed that the pre-video time points O1 (M = 27.05, SD = 15.64) and O2 (M = 28.15, SD = 16.26) had significantly lower performance than the post-video time points O3 (M = 59.80, SD = 28.67), O4 (M = 65.00, SD = 37.38) and O5 (M = 72.75, SD = 44.16). A paired samples t-test conducted to compare overall performance pre- and immediately post-video, O2-O3, was significant, $t(39) = -12.84$, $p < 0.05$.

Table 2. Descriptive statistics of mental and motor ability.

Variable	Mean (SD)
OSpan	32.05 (15.62)
Spot-the-word	42.68 (5.58)
Ravens SPM	48.47 (4.84)
Fitts Law	1.37 (0.20)
Inspection time	37.84 (13.85)
Total procedural knowledge	16.93 (4.09)
Total declarative knowledge	19.95 (5.06)

3.5.3 Three performance stages

To ascertain the influence of the three performances stages, a two-way repeated measures ANOVA was performed to compare the effect of 3 phase performance (preparations, throw, control) on 5 (time). There were statistically significant main effects of performance phase $F(2,78) = 146.015$, $p < .001$, and timepoint $F(4,156) = 63.872$, $p < .001$. Furthermore, there was a significant interaction of performance phase and timepoint $F(4,312) = 64.577$, $p < .001$.

To examine these effects further we performed plan contrasts. For the main effect of phase, performance was significantly higher in the throw phase than preparation (mean difference 8.6, $p < .001$) and control (18.16, $p < .001$), which differed from each other significantly (preparation>control, 26.76, $p < .001$) (See figure 9 and table 3). For the main effect of timepoint, there were significant differences between all-time points ($P > .05$) except time points 1 and 2 and time points 4 and 5 (See figure 10). These results emphasise the significance of the video tutor. This is further demonstrated in the interaction effect where all phases show increasing performance following the introduction of the tutor (see figure 11), but there is a marked difference in its effects between the three phases with preparation showing a far more dramatic change than the other phases.

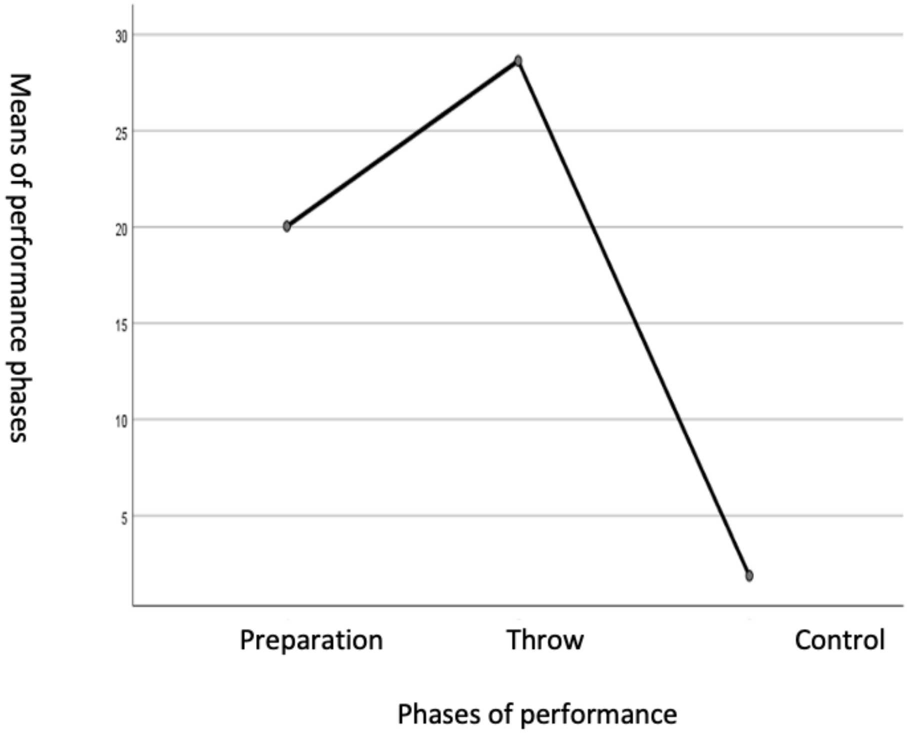


Figure 9. Mean plot for the three performance phases.

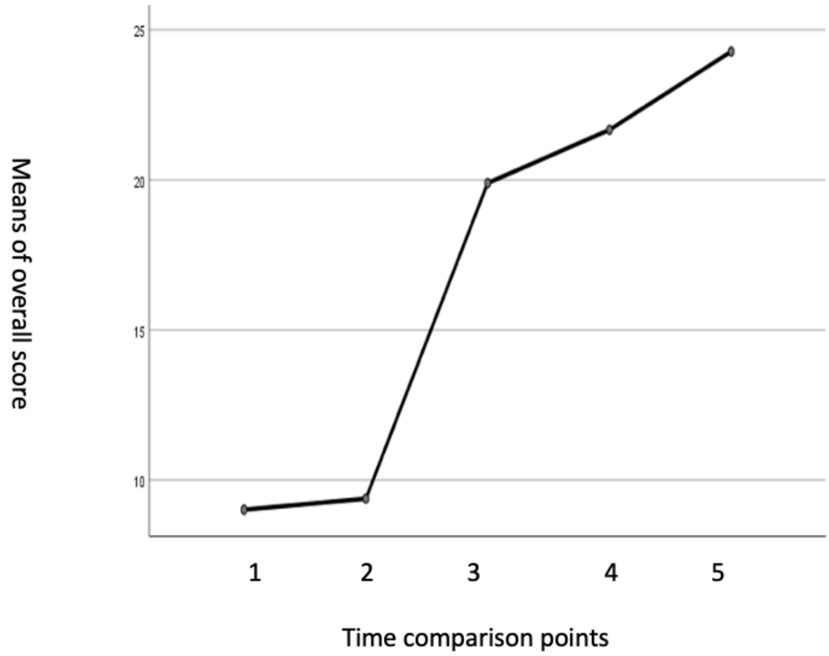


Figure 10. Mean plot for the five performance timepoints.

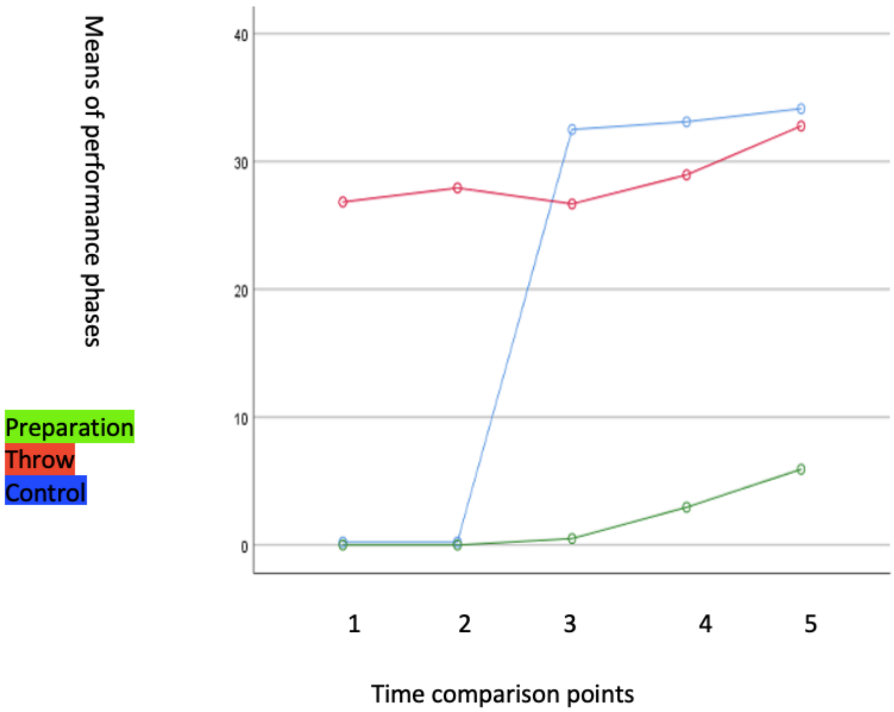


Figure 11. Mean plot for each performance phase at the five performance timepoints.

Table 3. Mean and standard deviation of phase and time points.

	Preparation		Throw		Control		Overall	
Time	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	0.23	0.89	26.83	15.63	0.00	0.00	27.05	15.64
2	0.23	0.89	27.93	16.27	0.00	0.00	28.15	16.26
3	32.50	16.48	26.68	15.56	0.50	1.52	59.80	28.67
4	33.10	16.43	28.95	18.89	2.95	9.33	65.00	37.38
5	34.13	15.61	32.78	20.11	5.93	12.29	72.75	44.16

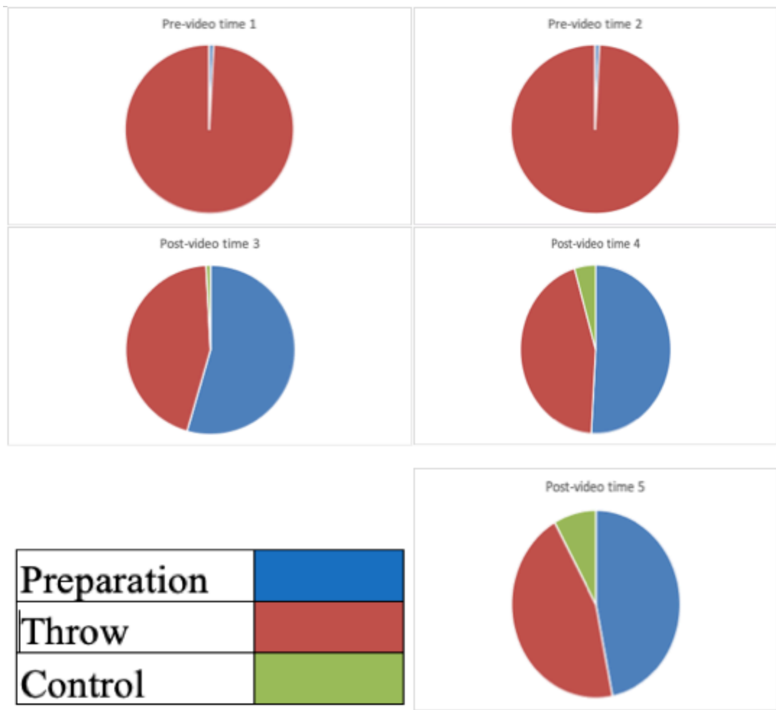


Figure 12. Bar chart of mean stages and overall performance in the hockey task.

3.5.4 The Relationship between single mental abilities and Hockey task.

As an initial analysis, I computed the bivariate correlations between overall hockey performance scores and the single mental abilities: (a) working memory, (b) spatial intelligence, (c) verbal intelligence, (d) perceptual speed, (e) psychomotor ability, (f) declarative knowledge and (g) procedural knowledge.

Working memory.

A Pearson's correlation revealed a significant relationship between OSpan scores and overall performance at all five-fixed comparison points. In addition, the correlation between OSpan and the stages (preparation, throw and control) of the Hockey task at some fixed points (see table 4) are also significant. Furthermore, it was found that O5 results (i.e., final performance) were significantly predicted by working memory scores, $R = .39$, $F(1, 38) = 6.66$, $p = .01$ (figure 13).

Table 4. Pearson's correlations between working memory and overall hockey performance and performance in task sub-components, as a function of time.

Time	Overall	Preparation	Throw	Control
1	0.314*	0.019	0.313*	.a
2	0.428**	0.019	0.427**	.a
3	0.391*	0.274	0.411**	0.226
4	0.379*	0.350*	0.265	0.381*
5	0.386*	0.392*	0.336*	0.344*
n	40	40	40	40

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
a. Cannot be computed because of low n.

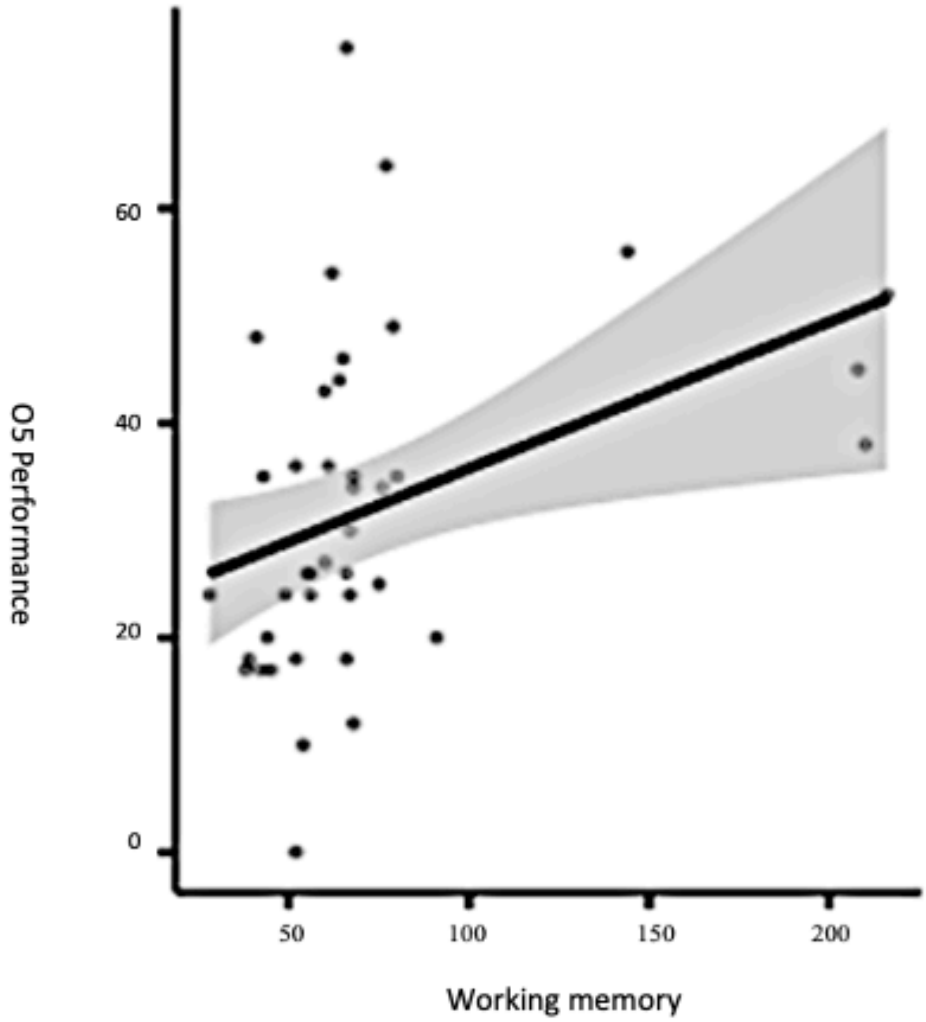


Figure 13. Regression between O5 performance and working memory.

Spatial intelligence

A bivariate correlation analysis between overall scores at each time measure and Raven's SPM indicated that only O3, the first measure post video intervention, was significantly correlated with Ravens SPM scores (r = .319, p = .045). The other overall scores pre-video O1, O2, and post video O4, O5 were not significant (p > .05). Furthermore, the stages at all measurement points were not significant (p >.05) (figure 14).

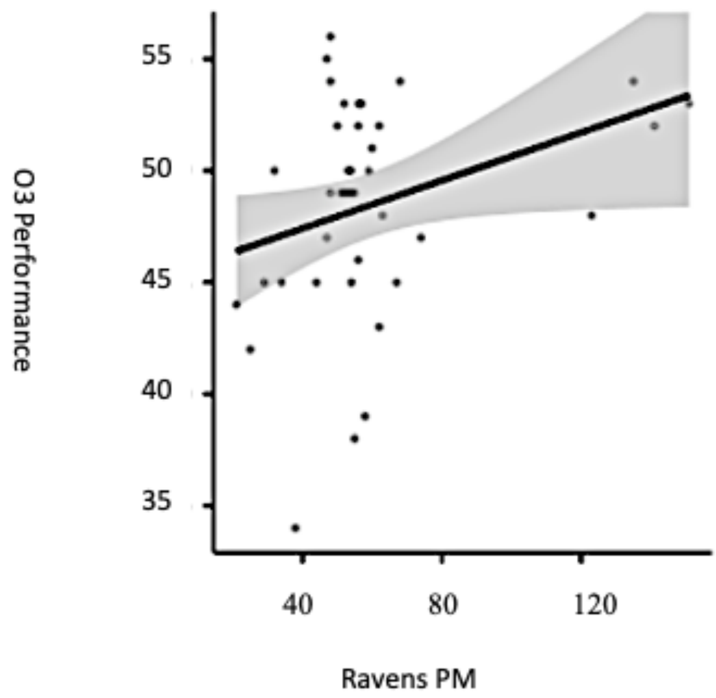


Figure 14. Regression between O3 performance and Ravens SPM.

3.5.5 Verbal Intelligence, perceptual speed, and psychomotor ability.

A bivariate correlation analysis between each time measured overall, preparation, throw, control scores and (a) Spot-the-Word, (b) Inspection Time and (c) Fitts's scores indicated a non-significant relationship ($p > .05$).

3.5.6 Declarative and Procedural Knowledge.

The mean declarative knowledge (DK) score across all sports indicated that participants possessed on average moderate or less prior knowledge (see table 5). The (perceived) procedural knowledge (PK) score indicated that twenty-six of forty participants (i.e., 65%) rated their average ability as moderate or lower. These Pearson correlations between this two sets of scores are ($r = .689$, $p < .001$). A bivariate correlation confirmed that neither total DK all scores (O1 to O5) and PS (O1 to O4) were not significant but

Performance at O5 is significantly negatively correlated with PK (r = -.361, p = .022), indicating O5 performance decreased with higher self-reported PK. Specifically, for ratings relating directly to hockey, all participants had moderate or lower DK and PK scores, in line with the inclusion criteria.

Table 5. Range, mean and standard deviation of Likert scores for Declarative Knowledge and Perceived Knowledge; each task was scored by a 5-point Likert scale: 1 (very low), 2 (low), 3 (moderate), 4 (high) and 5 (very high).

		Declarative Knowledge				Perceived Knowledge			
Sport	n	Min	Max	Mean	SD	Min	Max	Mean	SD
Basketball	40	1	5	2.80	1.02	1	4	2.40	1.01
Cricket	40	1	4	2.03	1.00	1	4	1.72	0.96
Field Hockey	40	1	3	1.38	0.63	1	3	1.30	0.65
Football	40	1	5	3.35	1.03	1	5	2.23	1.05
Hurling	40	1	4	1.07	0.47	1	2	1.03	0.16
Ice Hockey	40	1	3	1.38	0.67	1	2	1.15	0.36
Lacrosse	40	1	4	1.10	0.50	1	3	1.05	0.32
Netball	40	1	5	2.90	1.30	1	5	2.53	1.13
Roller Hockey	40	1	2	1.08	0.27	1	2	1.05	0.22
Tennis	40	1	5	2.88	0.82	1	4	2.50	0.85
Total		1	4	1.997	0.771	1	3.4	1.696	0.67

3.5.7 The Relationship between combined mental abilities and Hockey task.

Next, I tested the possibility that multiple psychometric measures combine to associate with performance. A multiple linear regression was performed associating mental abilities as independent variables (IVs: OSpan, Ravens SPM, Spot-the-word, Inspection Time, Fitts's task, declarative knowledge, and perceived knowledge) to predict the dependent variable (DV), performance O scores. Multi-collinearity analysis between IV's indicated two significant relationships: (a) Inspection Time (IT) and Fitts task (FL) (Pearson's $r = -.407$, $p = .023$) plus (b) total declarative knowledge and procedural knowledge (Pearson's $r = .687$, $p < .001$). As a consequence, inspection time and declarative knowledge were removed from the analysis.

The remaining IV's (OSpan, Ravens SPM, Spot-the-word, Fitts's task and perceived knowledge) were entered into a backward method multiple linear regressions for each measure of O performance. The final selected model contained all significant $p < 0.05$ IVs.

Table 6. Results of a linear multiple regression predicting overall performance.

Dependent Variable	Independent Variable	*t*	*p*	Unstandardized coefficient B	*F*	*df*	*p*	*Adj* R^2	*Cohen's* f^2
O5					9.28	2,37	0.001	0.298	0.425
	Constant	4.185	0.0	111,112					
	OSpan	3.368	0.002	1.295					
	Total procedural knowledge	-3.208	0.003	-4.712					
O4					6.997	2,37	0.003	0.235	0.307
	Constant	3.753	0.001	88.054					
	OSpan	3.096	0.004	1.052					
	Total procedural knowledge	-2.581	0.014	-3.349					
O3					5.749	2,37	0.007	0.196	0.244
	Constant	-1.093	0.281	-45.717					
	OSpan	2.564	0.015	0.678					
	Ravens	2.025	0.050	1.728					
O2					8.993	2,37	0.001	0.291	0.410
	Constant	3.83	0.000	37.633					
	OSpan	3.596	0.001	0.512					
	Total procedural knowledge	-2.809	0.008	-1.527					
O1					4.766	2,37	0.014	0.162	0.193
	Constant	3.57	0.001	36.689					
	OSpan	2.477	0.018	0.369					
	Total procedural knowledge	-2.226	0.032	-1.266					

Table 6 shows that the IV's OSpan and total procedural knowledge are significant contributors to O performance except for O3. Indeed, O5 had an adjusted $R^2 = 0.298$, indicating that 30% of the variance in O5 is explained by the IV's. The models including both OSpan and total procedural knowledge effect size (Cohen, 1988) had moderate to large Cohen's scores (*f2* = 0.193 to 0.425).

3.5.8 Motivation.

The motivation scores make it possible to verify that participants were sufficiently motivated (see *Appendix E* for the results of the motivation questionnaires). The mean values confirmed that all participants had moderate to high levels of task motivation (from $M = 3.20$ to $M = 3.95$). Mean task irritation was from moderate to low ($M = 3.20$ to $M = 1.78$) and interest was from high to moderate ($M = 3.78$ to $M = 2.93$).

3.6 Discussion.

This study investigated the hypothesis that mental abilities are influential in performance of a sports motor skill. The aim was to associate mental abilities and performance in a hockey task. The results showed that seven psychometric tasks were associated with hockey performance, to a different extent. Each mental ability is discussed in the context of the results.

3.6.1 Working memory.

The results indicated a positive correlation between working memory capacity (WMC) and overall performance, preparation, throw and control. In addition, WMC was also a significant contributing independent variable that predicted overall performance in the multiple regression. As a result, working memory is significantly associated with performance in a hockey task in novices.

The significant correlation between WMC and overall performance at each stage of the measures suggests that WMC is influential in performing this hockey skills, supporting the hypothesis that expertise is associated with higher mental abilities (Scharfen & Memmert, 2019). Furthermore, the ability to chunk elements together is associated with the speed of learning (Seidler et al., 2012). These elements are represented by the subcomponents of performance, preparation, throw and control.

When the hockey performance is reduced into subcomponents (chunks) denoting its stages of information processing (preparation, throw and control), these subcomponents are also significantly correlated with WMC at the time measures P4, P5 for preparation, C4, C5 for control and T1, T2, T3, T5 for the throw. Indeed, visual mappings involves working memory in novice expertise, suggesting that sequencing is important in motor learning (Anguera et al., 2010). Thus, WMC is relevant in learning the new skill through its effects on all the sub-components that constitute the skill.

Attempts to associate single mental abilities with performance are often the norm in MAMA investigations (Abd El Shakour, 2020; Deary & Mitchell, 1989; Ge, 1997; Paunescu et al., 2013), but as previously noted, there are many dimensions to expertise (Ackerman, 2014; Dreyfus et al., 1988; Gobet, 2015; Wai, 2014). Therefore, the idea that one factor may largely contribute to the performance is an oversimplification. Alternatively, some researchers have combined mental abilities to ascertain their influence on performance (Becker et al., 2012; Beech & Harding, 1990; Hunter & Burke, 1994; Lievens & Patterson, 2011; Martinussen, 1996). The notable difference between this study and previous research is that this thesis uses only mental abilities to associate with performance; previous research has combined both motor and mental abilities together. In this study, the multiple regression analysis indicated that WMC combined with procedural knowledge (PK) are significant predictors of O1, O2, O4 and O5 scores. The equation to predict performance at O5 is:

$$O5 = 1.30 \times WMC - 4.71\ PK + 111.11.$$

When performance scores increase from O1 to O5, the unstandardized B coefficient for WMC increases from 0.37 to 1.30, indicating more contribution from working memory as performance improves. Conversely, the PK is a negative coefficient and increases from –1.27 to –4.71. Thus, increasing (negative) influence performance score over time, this suggests that, with novices, the role of procedural knowledge negatively increases with improvement in knowledge.

3.6.2 Intelligence.

The influence of intelligence in performance is due to its association with non-specific planning abilities such as processing, storing, retrieval, combining, comparing, and enveloping new contexts and skills (Humphreys, 1979). To measure fluid and crystallized intelligence (Horn & Cattell, 1967), I used two psychometric tasks, the Ravens SPM and Spot-the-word, respectively. The association with overall performance resulted in the O3 score (i.e., the first overall score post video) being positively correlated with Raven's SPM as it is the abilities that Humphreys noted that would come to the fore. The linear multiple regression identifies Raven's and WMC as significant predictors succeeding that intelligence is influence at this O3 measure. The introduction of the video at this timepoint seems to create a reliance on spatial intelligence as well as WMC. Suggesting both are important when receiving instructions about a new skill, which may have implications for training and coaching. This is an area for future research. In addition, no further overall or subcomponents scores significantly correlated with Raven's SPM at any time measure. This result suggests that intelligence is important at O3 – the taking in of video information and understanding to enhance hockey performance. Therefore, Raven's SPM is relevant and may provide a superior ability to observe and structure the new information provided by the video, resulting in significant associations. Furthermore, the subcomponents were not significantly associated with Raven's SPM, indicating that stage task planning of performance does not engage intellectual abilities to the same extent as overall performance.

3.6.3 Task Knowledge.

The self-assessment of field hockey knowledge (declarative, procedural) results indicated a moderate to low score for all participants. In addition to ascertaining task domain knowledge, participants confirmed their experience in sports where common skills may apply to the current task. Across this broad range of sports, mean declarative knowledge (DK) and procedural knowledge (PK) were below the Likert score set for low, indicating the unlikelihood of skill transfer. These results confirmed that the methodology, which omitted any potential participant with task knowledge, was successful.

The bivariate correlation between DK and performance was not significant; but PK correlated negatively with O5 performance. In addition, PK was a meaningful contributor to the multiple regression models for O1, O2, O4 and O5. In each model, the negative direction for PK indicates that some participants overestimated their potential due to being novice performers with little task experience. This agrees with previous research into ability estimates in social and intellectual domains (Kruger & Dunning, 1999); these researchers hypothesized that this occurs because participants are unskilled and reach erroneous conclusions, thus decreasing their metacognitive ability and compounding their incompetence. This supports the notion that such outcomes are dependent upon the level of expertise and will diminish as knowledge is acquired.

3.6.4 Mental abilities.

The other mental ability variables – perceptual speed (Inspection Time) and psychomotor ability (Fitts's task) – were not significantly correlated with hockey scores. The abilities are presumably innate (Ackerman & Cianciolo, 2000). Mental abilities should be differentiated from variables that develop with practice, such as motivation (Coffee & Rees, 2011; MacNamara et al., 2010), cognitive skills (e.g. imagery, self-talk and goal setting) (Gill, 2016; Pocock et al., 2019; Van Raalte et al., 2016) and anxiety control (Hagan Jr et al., 2017). These variables are often associated with the maintenance of expertise. By contrast, the current research focuses on those mental abilities that may enhance skill acquisition.

3.6.5 Novice skill acquisition.

The results for intelligence, perceptual speed and psychomotor ability agree with Ackerman (1988), whose research utilizing an air traffic controller simulation identified that associations were dependent on the acquisition phase. He associated (a) phase 1: intelligence and novices, (b) phase 2: perceptual speed and intermediate expertise and (c) phase 3: psychomotor ability and expertise. The current research in hockey novices reported a significant phase 1 association (i.e., with WMC) and, as expected, no significant associations with variables hypothesized to play a role in phase 2 and 3.

The results support the contention that the phases of skill acquisition appear to be influential in ascertaining significant MAMA relations. At the novice phase, they provided insights into participants information processing throughout the Hockey task and the influence of the video coach. The overall pre-video scores were significantly different than the post-video scores; they were also significantly correlated with time, indicating that the intervention of the video provided necessary instruction to improve the task performance. The preparation and control stages were largely ignored pre-video but become considerable contributors towards performance post-video; both significantly increased over time. The throwing stage did not change significantly with time but became signification less in its contribution to performance, and the focus of attention was on preparation and control. Indeed, following the introduction of the video coach, the throw score at T3 decreased. This suggests that the supply of new task information (video coach) brings about a trade-off between multiple processes (stages) that are competing for the same working memory resource (Norman & Bobrow, 1975), and points to a redistribution of WM resources from the throwing stage to the preparation and control stage.

3.6.6 Participants' performance.

The participant selection procedure (no or little task knowledge) resulted in their novice status, ensuring that cognitive processes would be to the fore in performance. A complex hockey task was selected to maximise cognitive performance (Serrien et al., 2007). The initial strategy brought about poor performance, although results indicated that high motivational levels were maintained throughout; incidentally, this agrees with previous research demonstrating that future trials are not affected by early failure (Molden & Dweck, 2006) is particularly relevant in sport (Coffee et al., 2009).

The original tactics applied by participants before the video coach mostly involved the throw, resulting in O1 and O2 scores being entirely dominated by the T1 and T2 scores. Preparation activities were only performed by 7.5% of participants, and none attempted the control activities. Surprisingly, declarative, and procedural knowledge were not significantly related to pre-video performance, indicating that the initial screening of participants based on prior motor task knowledge was successful.

Previous research suggests that the likelihood of establishing significant associations between mental and motor abilities is dependent upon participants' phase of acquisition (Abd El Shakour, 2020; Ackerman, 1988; Deary & Mitchell, 1989; Paunescu et al., 2013). Therefore, the individuals' motor task status, different between novices and experts, should be determined before pairing a mental and motor ability. Generally, novices require considerably more cognitive input than experts (Serrien et al., 2007). Experts rely on less cognitive information as they have developed autonomous performance (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). This hypothesis is comparable with the developmental literature that compared the results of pre-pubescent and pubescent children. The number of significant cognitive and motor (?) correlations in pre-pubescent children exceeds those for pubescent (van der Fels, I. M. J. et al., 2015), suggesting that pubescent participants have relatively more expertise than pre-pubescent. Therefore, as individuals move towards expertise, the stronger MAMA relations associated with the novice phase decrease.

3.6.7 Video coach.

The introduction of the video coach initiates expert coaching and as expected, improved motor performance (Rascle et al., 2019). The availability of further task information led to significant changes in the approach to solving the task. Before the video, three participants had used the preparation activities to lift the ball over the obstacle, but immediately after the video, 100% utilized the preparation stage. The preliminary changes brought about by the introduction of the video coach resulted in large gains in overall performance; the timing of its introduction was to provide maximum cognitive engagement. Thus, it enabled greater available memory storage resources (Miller, A. et al., 1962; Miller, G. A., 1956) and increasing declarative knowledge (Berry & Broadbent, 1988). The consistent significant relationship between working memory and hockey scores suggests that the task provided a suitable range of information for the investigation, with the complexity of the hockey task bringing about a step-change in performance between pre and post video introduction.

3.6.8 Motor ability measures.

In this research, the motor ability scores were assessed by this researcher using two potential scoring methodologies (positional and technical), which were closely correlated. Spearman (1904) proposed that significant correlations between mental and motor abilities will occur when performance measures have a sound theoretical grounding. One possible mechanism is offered by the ACT-R theory, which assumes that motor abilities are encoded by IF-THEN rules, which link conditions to actions (Anderson, 2007). A comparison between both methodologies resulted in the positional method selection due to the higher significant correlation with performance scores. Notwithstanding this, the high correlation between scores indicates it would be possible to utilise either, in future research.

3.6.9 Limitations.

The limitations of MAMA research in sports largely revolve around the motor score calculation and the paucity of previous research for adults in this field. Although the hockey performance requires a coach with relevant skills, it is the factors (preparation, throw and control) that measures outcome, and these are set in a rule based on a theory of expertise. These factors are identified in appendix A.

The selected of athletes had a low hockey expertise ensuring less procedural knowledge. This current research may be lower that the real correlations.

3.7 Further research.

This study suggests it could be beneficial to include mental abilities when identifying talent. Future research could seek to confirm whether it is useful in combination with traditional TID methodologies in producing long-term benefits such as faster skill acquisition. Both bivariate correlations and the multiple regression analysis suggest that greater WMC could be a precursor to motor skill acquisition. Although the multiple regression formula only uses two of the seven mental ability factors investigated, other research indicates that variables such as WAIS performance IQ could be utilized (Fu, 2000; Li & Xiong, 1993; Sun, 1986; Zhu & Fang, 1988). In addition, the child developmental motor tests can guide potential methodologies to measure sports performance.

3.8 Conclusion.

This research hypothesized that mental abilities are fundamental in the performance of a motor skill, and I proposed a framework to investigate this relationship. Results indicated that (a) greater working memory capacity is significantly associated to performance in a hockey task; (b) spatial intelligence and working memory, when the training video was introduced resulting in better performance; (c) this relationship is occurred at the novice phase of expertise and its applicability at other phases (intermediate and expert) remains to be determined; and (d) the motor performance and proposed underlying components should be derived from a theory of expertise.

Overall, the results reflect the possibility of predicting future performance in novices by including participants with no experience, which increases the quantity of potential athletes available. Although further research across sports is required, this study supports the hypothesis that mental abilities influence early talent identification – a hypothesis which is neglected at the moment. The GB Team Olympic success has been based on a history of innovative and novel approaches (Rees et al., 2016), and future results may depend on embracing such ideas. Future aspirations should be to integrate mental abilities into the current TID framework in which mental abilities can be a contributory factor in validating TID.

Having proposed the potential influence of mental abilities on novice motor skill acquisition, this thesis now investigates the impact of physiological abilities in developing expertise by comparing traditional and detection talent identification processes in British cycling.

4 Chapter 4. Intermediate phase - Talent identification.

4.1 Introduction.

Talent identification attempts to identify factors that collectively predict an individual's future performance potential, selecting the best candidates for advanced training. Since the late 1990s, British cycling received funding through the UK National Lottery and commercial sponsorship from British Sky Broadcasting Group Plc. Both funding and focused talent identification measures have contributed to a considerable increase in Olympic medal success in cycling for the UK: Sydney 2000 (4 medals), Athens 2004 (4 medals), Beijing 2008 (14 medals), London 2012 (12 medals and Rio 2016 (12 medals). However, there is little available empirical data directly comparing the merits of the different talent identification processes utilized. The focus is on two methods used for talent identification at British Cycling, *traditional* and *detection*, which afforded the opportunity of directly comparing the outcomes for individuals selected based on either of these two different approaches.

Traditional talent identification methods consist of selecting athletes who are currently involved in their chosen sport (Lidor, Côté, & Hackfort, 2009)) by using achievement measures (e.g., race results, rankings, etc.), expert assessment of performance by coaches and talent scouts within that sport. Thus, motor performance is a key factor in selection and comparative levels of initial motor learning have been achieved through interaction with the task. In sports, the traditional talent identification methodology is the predominant pathway for identifying potential, and 80% of elite performers were selected using this approach in 12 major sports (English Sports Council, 1998).

An alternate approach is talent identification by detection, which measures components of successful performance (e.g., power, anaerobic capacity, etc.). It is possible to apply this approach to those with no history in the defined sport (Williams, A. M. & Reilly, 2000) and those displaying embryonic abilities with little task knowledge. This approach thus potentially widens the available pool of performers to any participant willing to attend testing. Furthermore, the generic tests do not require expert facilities and can occur in schools, halls and clubs. Therefore, this provides the potential to identify talented athletes with no prior experience and experienced late developers.

British Cycling talent development pathway, the "Rider Route", utilizes these two talent identification methodologies and provides suitable data that facilitates the comparison of traditional and detection talent identification. The traditional route consists of competitive opportunities resulting in cyclists positioning themselves in the British Cycling Rider Route talent development pathway, which consists of regional and national development centers; placement depends upon maturity and experience. Selection occurs from the age of five (British Cycling, 2021), and competitive results determine progression into the Olympic Development Programme based on race results performance. The detection route is the Talent Team Programme, a multi-Olympic event initiative by UK Sport and coordinated by each governing body (in this case, British Cycling) that identifies athletic potential from a range of generic physical and skill-based tests. Identification occurs by testing candidates between the ages of 11 to 16 years in schools or performance centers. Testing ethics stipulates that the age of 11 years is the earliest testing age (British Cycling, 2021). The selection consists of physiological performance on a Wattbike (turbo trainer), with assessment measures such as power output and peak cadence.

Upon selection, cyclists join the Rider Route in preparation for membership of the Great Britain Cycling Team. Apart from age and experience-related differences, the process of motor development for both groups follows a similar path (British Cycling, 2020).

In part, the theoretical debate in which researchers focus on the importance of practice (Ericsson et al., 1993; Ericsson, Prietula, & Cokely, 2007; Helsen, Starkes, & Hodges, 1998; Helsen, Hodges, Van Winckel, & Starkes, 2000; Law, Côté, & Ericsson, 2007) or talent (Hambrick, Burgoyne, Macnamara, & Ullén, 2018; Lombardo & Deaner, 2014; Staff et al., 2020) in achieving expertise. Those researchers who emphasize the importance of practice largely de-emphasize the role of talent. Ericsson et al. (1993) stated that, for children, early practice is significant and must coincide with biological and cognitive development. Furthermore, early specialization is relevant in children, as later starters would not be able to "catch up" (Ericsson et al., 2007). However, there is still a considerable debate as to the impact of early practice on expertise (Baker, Joseph, Cobley, & Fraser-Thomas, 2009; Crisp, 2019; DiFiori et al., 2017; Yustres et al., 2019) and negative outcomes have been reported, including its potential to reduce overall motor skill development (Myer et al., 2016) and its influence in facilitating burnout and injury (Malina, 2010).

By contrast, researchers who argue for a contribution from talent in acquiring expertise highlight the importance of critical periods (Chassy & Gobet, 2010; Tucker & Collins, 2012), which are hypothesized to rely upon genetic programming (Viru et al., 1999). Such talents result in accelerating expertise (Lombardo & Deaner, 2014) and providing an opportunity for early diversification (Staff et al., 2020) that can lead to a growth in motor development (Myer et al., 2016).

Researchers investigating elite performers have focused on developmental history and talent identification programmes for an explanation of individual differences (Ford & Williams, 2012; Güllich & Emrich, 2014; Güllich, 2014; Güllich, 2017), although direct comparisons between elite performers having followed these two routes have been infrequent (Barth, Emrich, & Güllich, 2019). To compare both selection methods, the methodologies developed to assess the Deliberate Practice hypothesis (Ericsson et al., 1993) were utilized, applying its definition of the start of practice and the attainment of expertise. This enabled us to calculate a chronological measure for expert achievement. I termed this the “period to excellence”, which consisted of practice and recovery periods associated with developmental expertise (Bompa & Carrera, 2005; Gibala, MacDougall, Tarnopolsky, Stauber, & Elorriaga, 1995). These recovery periods are important in reducing overtraining and injury as well as allowing other life activities (Grandou, Wallace, Impellizzeri, Allen, & Coutts, 2020) and do not include practice that mitigate burnout (Lopes & Vallerand, 2020).

To quantify the effectiveness of these talent identification methods in selecting potential elite performers a comparison of how quickly cyclists acquired expertise (elite proficiency), operationalized as their period to excellence. Anticipating that a talent selection process, which focused on the specific task demands, would lend itself to the quicker acquisition of expertise. The hypothesis is that those individuals selected by detection talent identification would develop faster than those selected using traditional talent identification.

4.2 Methodology.

4.2.1 Participants.

The study includes data on all 27 cyclists (12 women and 15 men) selected for Team GB in the London 2012 Olympics. Cyclists were aged 17 to 34 years (Men: $M = 20.36$, $SD = 1.23$; Women: $M = 21.23$, $SD = 4.62$) when they achieved expertise. The starting point of deliberate practice ranged from 5.00 to 27.02 years of age. The cyclists were divided into two talent identification groups: detection talent identification ($n = 9$) and traditional talent identification ($n = 18$). A comparison of medals awarded shows that athletes selected by detection talent identification gained three individual medals and five team medals and those athletes selected by traditional talent identification gained five individual medals and five team medals.

4.2.2 Data Collection.

All Team GB cyclists selected for the London 2012 Olympics, I collected their date of birth as well as the starting and finishing points of deliberate practice. The following sources were used. First, the British Cycling (n.d.) website contained riders' biographies and provided many basic data points such as age and cycling history. Second, public domain biographical information was obtained from Internet sources, local newspaper reports, cycling magazines and social media, with particular focus on the cyclists' initiation of deliberate practice. Finally, the British cycling website provided a list of athletes' agents and representatives, who were contacted with the following questions regarding the athlete they represented: (a) When did you start to focus on your sport? (b) At what age were you first coached for your sport?

and (c) Did you train at any other sport prior to you focusing on your main sport? If yes, which sport(s)?

4.2.3 Measures.

The deliberate practice framework parameters were utilized (Ericsson et al., 1993) to calculate cyclists' period to excellence, which was defined as the difference between the starting point of formal training (defined as joining a club and/or obtaining regular coaching) and the first selection in a senior international competition (either the Commonwealth games, European championships, World Cup or the Olympic games).

To estimate when cyclists first joined the British cycling talent identification programme, publicly available information on the British cycling website and/or athletes' personal websites. Cyclists' talent identification selections were divided into traditional and detection. Traditional talent identification cyclists were selected based on competitive results and were placed in the Riders Route at a stage that was consummate with their performance and experience. Detection talent identification cyclists were selected based on threshold measures, usually through testing days in the school environment; these athletes had no formal competitive experience. Upon selection, they entered the Olympic talent team programme, the initial stage of the Riders Route.

4.3 Data analysis.

A linear regression analysis was used to estimate the extent to which the starting age predicted period to excellence. As the data violated the assumption of normality, comparisons between the traditional identification group and the detection identification group were made using Mann-Whitney U tests. A variance ratio test identified whether the standard deviations of the two groups differed. A single sample t-test was used to determine whether the observed period to excellence other than 10 years.

4.4 Results.

Tables 7, 8, and 9, show the means for traditional and detection talent identification. Table 7 displays the results for the period to excellence, table 8 for starting age, and table 9 for expertise age.

Table 7. Period to excellence for traditional and detection methods.

	Period to excellence				
Talent identification method	N	Mean	SD	Minimum	Maximum
Traditional	18	9.94	5.55	5.00	27.02
Detection	9	5.79	2.32	3.24	9.86

Table 8. Starting age for traditional and detection methods.

	Starting age				
Talent identification method	N	Mean	SD	Minimum	Maximum
Traditional	18	11.23	5.55	5.00	27.02
Detection	9	14.12	1.45	11.01	16.01

Table 9. Expertise age for traditional and detection methods.

	Expertise age				
Talent identification method	N	Mean	SD	Minimum	Maximum
Traditional	18	21.17	3.75	16.71	33.70
Detection	9	19.91	1.24	18.25	22.87

4.4.1 Period to Excellence as a function of Starting Age.

A linear regression was computed with starting age as predictor and period to excellence as criterion variable. The regression equation was: period to excellence = 15.250 – (.549 × starting age); $p < .001$; adjusted $r^2 = .541$. Thus, each additional starting year *reduced* period of excellent by about half a year. After removing two athletes who started after 20 years of age (20 years and 27 years, respectively), the equation becomes: period to excellence = 19.250 – (.937 × starting age); $p < .001$; adjusted $r^2 = .821$. The later start resulted in faster expertise and each additional starting year now reduces period of excellent by nearly one entire year. Inserting the relevant mean starting age (respectively, 11.23 years and 14.12 years) in the regression equation yields a predicted period to excellence of 8.73 years for traditional talent identification and 6.02 years for detection talent identification.

4.4.2 Starting and Expertise Age as a function of talent identification pathway.

Shapiro-Wilk test of normality indicated that the data violated the assumptions of normality: Period to excellence, W = 0.926, $p = 0.054$; Start Age, $W = 0.854$, $p < 0.001$; End Age, $W = 0.739$, $p < .001$. A Mann-Whitney U test was conducted to compare the starting age and expertise age for detection ($n = 9$) and traditional talent ($n = 18$) identification selection processes. Results indicated that there was a significant difference for starting age (*U* = 37.0, *p* = 0.025) between detection talent identification (*Mdn.* = 14.01) and traditional talent identification (*Mdn.* = 10.51) but there was no statistically significant difference with respect to expertise age *(p* = 0.348). Interestingly, an F-test showed that, with starting age, the standard deviation was higher with traditional talent identification (*SD* = 5.55) than with detection talent identification (*SD* = 1.45), $F(17, 8) = 14.65$, $p < .001$. Similarly, the standard deviation for expertise age was higher with traditional talent identification (SD = 3.75) than with detection talent identification (SD = 1.24), F (17, 8) = 9.15, p < .005.

4.4.3 Period to Excellence as a function of talent identification pathway.

The hypothesis was that the speed of expertise achieved in British Cycling talent identification was quicker with detection when compared with traditional methods. To attain an equitable comparison of the different talent identification methodologies, all data was removed from the traditional talent identification group with a starting age of less than eleven, which is the minimum age that athletes enter the training programme based on talent identification. A Mann-Whitney U test indicated that the period to excellence was quicker in detection talent identification (*Mdn.* = 5.4, *n* = 9) than traditional talent identification (*Mdn.* = 7.2, *n* = 9), *U* =16.0, *p* = 0.031.

All nine cyclists (100%) selected using detection talent identification and ten traditional talent identification cyclists (56%) reached elite level in under 10-years. A single sample t-test was conducted to determine if there was a statistically significant overall difference between the observed period to excellence and the ten-year period of deliberate practice predicted by Ericsson et al. (1993) . The period to excellence for the entire sample (*M* = 8.55 years, *SD* = 3.50 years) was statistically significantly lower than 10 years, t (26) = -2.15, p = .041.

4.5 Discussion.

This paper tested the hypothesis that the time required to become an expert cyclist varies depending on the type of talent identification methodology (traditional or detection) used for the initial selection. The data from the cyclists representing Team GB in Cycling at London 2012 Olympics selected by the British Cycling talent identification programme was used. I predicted that those cyclists selected by the detection talent identification route would develop to expertise quicker (shorter period to excellence) than those chosen using the traditional talent identification route. The results indicate that detection (measures of power output and cadence) is superior to traditional TID (race result rank), at the intermediate phase.

The outcomes show that the median period to excellence of British Cyclists representing Team GB at London 2012 was significantly quicker when selection was made by detection talent identification (*Mdn*. = 5.4 yrs.) than traditional talent identification (*Mdn*. = 7.2 yrs.). This result indicates that the introduction of detection measures in the Talent Team Programme by UK Sport has resulted in Cyclists acquiring elite expertise faster than traditional talent identification methods. Therefore, it is possible to postulate that faster motor learning and development may be a consequence of attendant talent and an interaction with starting age, individual differences, and talent identification methodology. This result is inconsistent with previous claims that the journey to expertise is 10 years (Ericsson et al., 1993) and concurs with previous sport research such as sprinting plus track and field (Lombardo & Deaner, 2014; Staff et al., 2020) indicating that the average mean period to excellence was less than 10 years, which suggests that talent contributes to performance.

4.5.1 Starting Age.

When comparing talent identification methodologies in cycling using the period to excellence measures, the difference between detection talent identification (M = 5.79 yrs., n = 9) and traditional talent identification (M = 9.94 yrs., n = 18) resulted in a 4.15-years acceleration of expertise. The 4.15-years acceleration in the speed of expertise for detection talent identification is calculated by a later starting age and the faster motor development period. The later starting age accounted for 2.89 years = (14.12 – 11.23) (see table 7). These results question the necessity of early practice in acquiring expertise, which has been claimed to be significant for becoming an Olympic medalist (Ericsson et al., 1993; Ericsson et al., 2007).

A Mann Whitney U test also indicated a significant difference between start age for detection (*Mdn*. = 14.01 yrs.) and traditional (*Mdn*. = 10.51 yrs.) talent identification. The ethics that guide the minimum physiological testing age in children led us to anticipate a considerable contribution from the starting age in the overall acceleration of expertise. This research identifies eleven years as the earliest testing age for detection talent identification in British Cycling but accepts children as young as five into their traditional talent identification program (British Cycling, 2021). The six-year difference between these two talent identification methods potentially results in detection cyclists having a greater diversification on skills which can have a positive effect of skill acquisition (Güllich, 2014; Güllich, 2017; Staff et al., 2020; Vaeyens, Güllich, Warr, & Philippaerts, 2009). Conversely, traditional cyclists have specialized in their sport from an early age. The results indicate that this was not advantageous, which agrees with research across multiple sports (Baker et al., 2009; Crisp, 2019; DiFiori et al., 2017; Yustres et al., 2019).

A comparison of cyclists from both talent identification methods with similar starting dates indicated a significant difference between the period to excellence in detection talent identification (*Mdn.* = 5.4) when compared with traditional talent identification (*Mdn.* = 7.2). Thus, a later engagement in the development of expertise resulted in faster skill acquisition, which supports the idea of critical periods in which individuals are likely to make an above normal response to exercise (Armstrong, Williams, Balding, Gentle, & Kirby, 1991; Baxter-Jones, 1995; Malina, 1994; Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004). This concept is hypothesized to be reliant upon genetic programming (Viru et al., 1999) and suggests that developmental factors should align with task demands to facilitate skill acquisition (Armstrong et al., 1991; Baxter-Jones, 1995; Malina, 1994; Malina et al., 2004). This research suggests that the critical period for cycling detection talent identification is from 11 to 16 years.

Therefore, indicating that a later starting age will be a consistent feature of research using physiological measures and that critical periods should be a feature of talent identification processes throughout sports. For example, a critical period of six years (11 to 16 years) for detection results is a more focused approach to talent identification when compared with the broad range of 22 years (5 to 27 years) of traditional talent identification, considerably narrowing the target field for selection.

4.5.2 Expert Age.

Those participants selected by detection talent identification resulted in acquiring expertise 1.26 years (i.e., 21.17 – 19.91) quicker (see table 8). The results indicated that the period to excellence was significantly quicker for the detection cyclists. Therefore, the concept of critical periods (Viru et al., 1999) leads us to speculate that the synergy between talent and developmental factors which facilitated the later starting date and the specialized training also brought about enhanced opportunities for the further development of expertise (Svetlov, 1972). Although this research indicates acceleration in expertise, this does not necessarily occur at a uniform rate across the acquisition period (Scott, 1986).

4.5.3 Genetics and Individual Differences.

British cycling utilizes measures of power output and anaerobic capacity within detection talent identification, considering these factors important for cyclists progressing faster in sport. An often-cited definition of talent states that it has "its origin in genetically transmitted structures" (Howe, Davidson, & Sloboda, 1998, p. 406). Some researchers state that "the potential impact of genetics could be great, and thus further research in this area is warranted, in particular in relation to specific performance genes, training/learning genes and genes underpinning injury proneness" (Rees et al., 2016, p. 1044). Associations between component abilities and performance have been identified by genetics research, which has shown that a positive genetic profiling benefits performance. The ACE gene (Angiotensin-converting enzyme) has been associated with positive cardiovascular system and skeletal muscle adaptations (Montgomery et al., 1998; Yang et al., 2003). The ACTN3 gene (Alpha-actinin skeletal muscle isoform 3) has been found to be beneficial in elite power and sprint athletes (Chan et al., 2008; Yang et al., 2003) and the CKM gene (Creatine Kinase Muscle) has been associated with the response to training of VO_2max (Pennington Biomedical Research Centre, 2013). Although the current research suggests that detection talent identification leads to acceleration in acquiring expertise, it does not suggest that it is talent alone that determines the period to expertise. Research that specifically identifies the genetic determinants of expert performance is still very much in its infancy (see Ahmetov & Fedotovskaya, (2012). In addition, it is likely that expert performance will be a result of a combination of genes rather than a single gene variant.

Indeed, the explanation of critical periods in acquiring motor expertise relies upon genetic programming for the appearance of new events such as growth, maturation, and development (Viru et al., 1999). Therefore, innate individual differences can lead to variability in the period to excellence. The results indicate the implementation of the Talent Team Programme by UK Sport as applied to British Cycling affects the speed of motor learning and development, indicating the potential for it is utilized across multiple sports (see also https://www.uksport.gov.uk/our-work/talent-id/previous-campaigns).

4.5.4 Selection of talent identification measures.

Traditional talent identification occurs by choosing high performing children with the expectation that their motor learning and development will lead to the same comparative expertise as adults. As sports developed, talent identification practitioners evolved their approach. Coaches deconstructed expertise into information processing components (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977), reassembling into the complete performance (Griffin, n.d.; Lydiard & Gilmour, 2000). Tests involving subcomponents of cycling are identified as significant contributors to performance (Paton & Hopkins, 2001; Wattbike, 2010). However, it is likely that contributions from other factors such as anthropometric measures (Foley, Bird, & White, 1989) and genes not associated with these measures, (Davids & Baker, 2007) influence these results.

Thus, the measuring of subcomponents broadens the number of potential cyclists at the sampling period of 11 to 16 years of age, offering the opportunity to all within that age group to try-out. Selection by the appropriate genetic profile provides the opportunity for selection from other sports with a genetic profile akin to cycling. The qualitative analyses of the two track endurance gold medalists selected by these measures agree with this suggestion; both had keen interests in athletics and swimming before being tested in cycling. These results conflict with the idea that expertise is associated solely with practice (Ericsson et al., 1993) and agree with the hypothesis that innate ability contributes to expertise (Hambrick et al., 2018). Indeed, innate ability can accelerate expertise and is identifiable by specific talent identification methods.

It seems you might also consider how the different talent ID method may broaden the net at different sampling periods such that it identifies people with the appropriate genetic profile and potential for cycling but who for whatever reason may have been interested in a different sport and/or just did not realize that cycling fits their body type, etc.

4.5.5 Period to Excellence.

Theorists who do not subscribe to a single factor hypothesis to explain expertise – the practice vs. talent dichotomy – endorse a multi-component explanation to expertise (Ackerman, 2014; Gobet, F., 2015). Suggesting that the measure of the period to excellence offers a more holistic approach to identifying the time applied to acquiring expertise, as this not only includes practice but also recovery periods, which allows for physiological adaptations. Therefore, given the same level of expertise, it would be expected that times for the period to excellence would exceed deliberate practice.

There are pitfalls in determining the starting point of deliberate practice and correspondingly the measures, which are utilized to ascertain the period to excellence measure. This is highlighted in the data, by the responses from GB's most decorated Olympic cyclist to the following questions:

When did you start to focus on your sport?

Response: 17.

At what age were you first coached for your sport?

Response: 24.

Ericsson et al. (1993) suggest that the starting point can be identified by either of these questions; yet the 7-year variation in this response highlights the difficulty in obtaining the actual starting point of deliberate practice. As a result, the most cautious approach was followed by using the date the athlete first focused on their sport.

In addition, in the achievement of expertise the first senior international competition was selected. Some athletes make the transition from junior to senior competition seamlessly and therefore the junior achievement date would seem to be applicable. Considering the importance of physiological capabilities in the cycling task, it would be prudent to choose the senior, or later attainment measure.

There are also operational differences between the calculation of the deliberate practice period (Ericsson et al., 1993) and period to excellence. This is largely brought about by the different domains of research, e.g., violinists and cyclists. Deliberate practice is defined as effortful activities designed to optimize improvement; it can be intermittent and is a measure of practice activities only. The period to excellence takes into account practice, injury and physiological adaptation that require rest (Rivera-Brown & Frontera, 2012). Ericsson recently added to the deliberate practice hypothesis by stating that "the most important point is that high-intensity physical activity can only be maintained for a short period and thus its effectiveness for stimulating change and improvement of performance cannot be measured by its duration" (Ericsson, 2020, page 170). Conversely, the results indicate that bringing about positive improvements in motor development are important and that high intensity physical activity in combination with rest, contributes to expertise in cycling; for examples isometrics (Kordi et al., 2020), weight training (Tiberiu et al., 2020) and oxygen uptake (Paton & Hopkins, 2001) and should not be dismissed.

In order to attain cycling expertise, research suggests that maximal and submaximal physiological performance needs to be achieved (Mujika & Padilla, 2001). To realize these physiological milestones, it is possible to apply a "power law" (Newell & Rosenbloom, 1981) equating the amount of time in acquiring expertise (the period to excellence) with physiological performance. Thus, the greater time applied equated to larger physiological gains. Indeed, cycling research indicates that the levels of aerobic fitness and off-road cycling performance were significantly associated (Impellizzeri, Rampinini, Sassi, Mognoni, & Marcora, 2005).

4.5.6 Deliberate practice.

Although it may not seem immediately clear as to why research into music expertise should be used in sport, it is evident from the popularity of the deliberate practice framework in sports research that many researchers have taken the intention of Ericsson et al.'s (1993) paper to refer to expertise in general. Furthermore, in that paper the section in the literature review "Distinct Physical Characteristics of Elite Performers" (Ericsson et al., 1993, p. 394) largely focuses on the physiological adaptation that become apparent as sport expertise is attained – heart, lungs, bones and muscles including the quantity of fast and slow twitch fibres. Therefore, it is not surprising that it has consistently been applied to sport (Baker et al., 2005; Helsen et al., 1998; Helsen et al., 2000; Hodges, Kerr, Starkes, & Weir, 2004; Lombardo & Deaner, 2014; Ward, P., Hodges, N.J., Williams, A.M. & Starkes, J., 2007).

The deliberate practice hypothesis largely claims that talent (except height and weight in some sports, and the ability to engage in long durations of deliberate practice) does not contribute to the speed of acquiring expertise and that a minimum of 10 years of motivated practice is required to acquire expertise (Ericsson et al., 1993). The current research suggests a different hypothesis: it takes less than 10 years to achieve expertise, with disparities being a function of individual differences, in part related to talent (Lombardo & Deaner, 2014; Staff et al., 2020) but also associated with sport selection (Baker et al., 2005; Helsen et al., 1998).

4.5.7 Medalists.

At the London Olympics, twenty-seven GB cyclists were selected across events that included track sprint and endurance, time trials, road race, BMX and mountain bike. The details of the medals awarded are listed in table 10. Eighteen were selected from the traditional group, of whom seven won medals consisting of eight gold and two bronze medals in of track and time trials only. British Cycling did not win a medal on either the road race, BMX or mountain biking.

Table 10. Talent identification and its contribution to the Cycling medal total at London 2012 Olympics.

	Quantity of Events		Medal (Gold-Silver-Bronze)	
Event	Traditional	Detection	Traditional	Detection
Track Sprint	3	5	2-0-0	4-1-0
Track Endurance	7	4	5-0-1	3-0-0
Road Time Trial	3	1	1-0-1	0-0-0
Road Race	4	1	0-0-0	0-1-0
BMX	2	0	0-0-0	0-0-0
Mountain Bike	2	0	0-0-0	0-0-0
Total	21	11	8-0-2	7-2-0

The detection group consisted of nine of participants, of whom two had no prior experience, and seven had some cycling experience. These participants were selected to compete in track sprint, endurance, and road race events. They won 45% of Team GB Cycling medals at London Olympics 2012 (see table 10). The two inexperienced cyclists both won track team pursuit Gold Medals. Five with experience won five golds and two silvers in track and road race events; two cyclists did not win any medal.

At the 2012 London Olympics traditional talent identification follows the historical convention of selection since the first Modern Olympic Games in 1896, approximately 116 years ago. Conversely, detection identification has been taking place for at only about 12 years. The medal haul for talent identification method in London was yielded ten medals for traditional talent identification and nine detection talent identification. Thus, it would seem detection talent identification has a future in selecting Great Britain's next Cycling Olympians.

4.5.8 Limitations.

The sample size was relatively small, which might result in skepticism with respect to the generalization of the results into other fields. However, it should be noted that it is normally accepted that sample size is context-dependent (Lenth, 2001) and the statistical tests were suited to small populations (Field, 2009). While not perfect, the methodology is recommended in hard-to-reach populations such as elite athletes (Staff et al., 2020). To mitigate this, the methodology used online data collection methods, which are considered at least as good as in-person data (Casler, Bickel, & Hackett, 2013; Gosling, Gaddis, & Vazire, 2007; Vazire & Gosling, 2004).

The current research provides an important comparison between talent identification methodologies within British Cycling. Surprisingly, such comparisons are not published or are not the norm in performance overviews and the assessment of resource efficiency. Is there an expectation that detection will produce expertise and the comparison with traditional methods is unproductive? Researchers have suggested that talent identification consists of highly rationalized myths rather than highly efficient norms (Barth et al., 2019); these results suggest that the lack of such research is a good example of this attitude.

4.6 Summary and Conclusions.

What are the implications for resources utilized in developing methods that contribute to the acceleration of expertise? The objective of talent identification is to assess athletes, identify potential for senior elite performance and recruit them into sport-specific programmes. Once athletes are selected, the financial imperative is to ensure that all practical means are used to accelerate the acquisition of expertise. This involves optimizing coaching, competitive opportunities, medical and scientific interventions (Vaeyens, Güllich, Warr, & Philippaerts, 2009) . The detection methodology has a number of benefits for talent identification: (a) increasing the pool of athletes suitable for potential Olympic selection, potentially leading to greater competition for places and higher performance standards; (b) increasing the efficiency in the allocation of resources brought about by faster skill acquisition; (c) providing information on associations between genetic factors and likely performance outcomes; and (d) introducing a wider range of potential participants to Olympic sports. UK Sport has utilized this methodology across other Olympic sports (https://www.uksport.gov.uk/our-work/talent-id). Further research would be required to determine if these results could be generalized across all sporting domains.

The results indicate at the intermediate phase, detection is superior to traditional TID. That the speed of acquiring cycling expertise is quicker for cyclists selected using detection compared with traditional talent identification, and so it is an effective additional basis for candidate selection. Thus, providing support for the introduction of the Talent Team Programme by UK Sport as a precursor to individual Olympic Sports talent identification programmes. Nonetheless, significant success is also achieved by candidates selected by the traditional approach indicating that the two approaches are well suited in acquiring expertise. Furthermore, it questions the assumption that early learning is necessary for acquiring expertise and supports the hypothesis that both critical periods and therefore genetic factors align with tasks, contributing to accelerating the acquisition of expertise in sports. Talent is a rare commodity in motor learning and development, and to ignore athletes' genetic potential in talent identification is not rational. It is hoped this will promote debate into a more rounded understanding of factors that contribute to the acceleration of expertise.

Thus, so far this thesis has investigated talent at the novice and intermediate phases in acquiring expertise from the perspectives of components that contribute to overall psychological and physiological performance. The next chapter considers the influences of acquiring expertise associated with elite athletes; the parameters of deliberate practice are utilized to investigate the speed of acquiring expertise in track and field athletics. The research investigates the impact of the human energy system (aerobic and anaerobic), event type and previous sporting experience.

5 Chapter 5. Expert phase – The speed of acquiring expertise.

5.1 Introduction.

How long does it take to become an Olympian? Why do some athletes achieve top performance levels while others do not? More generally, what are the differences between individuals that attain expert performance in domains such as science, the professions, the arts, and sports, and those that do not?

Three main approaches have aimed at answering these questions. The first emphasizes innate potential and talent (Gardner, 1983). This approach has recently received strong support from research in genetics and genomics showing that some abilities – both physical and psychological – depend on innate factors (Ahmetov & Fedotovskaya, 2012; Tucker & Collins, 2012). The second approach focuses on the role of environment and practice (Bloom, 1985; Simon & Chase, 1973). It emphasizes the role of teachers, family and wider environment, practice, and feedback. The third approach considers aspects linked both to talent and practice, and highlights the interactions between them (Gobet, 2015; Simonton, 1999; Ullén, Hambrick, & Mosing, 2016). It also highlights the time-dependent dynamics of the acquisition of expertise, such as the possibility that small initial variations might lead to large difference years later.

Over the last two decades, the deliberate practice approach has been particularly influential. It states that domain-specific expert levels of performance can only be attained through sustained investment in activities deliberately designed to improve performance (Ericsson et al., 1993). Irrespective of initial individual differences in talent or experience, the right kind of practice will produce expertise. Although individually focused, deliberate practice requires teachers, training material, and facilities. The practice is domain specific, effortful, and not inherently motivating or enjoyable, and can only be sustained for limited periods so that the exhaustion point is not reached. Only those hours spent practicing alone count as deliberate practice; team practice and competition are explicitly excluded. It is assumed that talent and previous experience do not accelerate the speed of acquiring expertise performance and that performance is a monotonic function of the amount of time devoted to deliberate practice: "the adult elite performance, even among individuals with more than 10 years of practice, is related to the amount of deliberate practice" (Ericsson et al., 1993, p. 373).

Practice is optimal when tailored to a specific domain; therefore, expertise in one sport is not useful in another sport, and early specialization is a requirement for success. Building on Simon and Chase's (1973) estimate, Ericsson et al. (1993) state that an important prediction of the deliberate practice framework is that "… expert performance is not reached with less than 10 years of deliberate practice" (p. 372); this period to excellence of 10 years (or 10,000 hours) is a minimum that applies across all domains. Thus, they consider the period of expert attainment in mathematics, sport, and teaching to be the same, given appropriate levels of deliberate practice. This prediction has been repeated in many publications about deliberate practice. For example, Ericsson, Prietula, and Cokely (2007, p. 119) write "… the research shows that even the most gifted performers need a minimum of ten years (or 10,000 hours) of intense training before they win international competitions" and, specifically in relation to competing in the Olympics, that (i) "…. it is almost impossible to beat the ten-year rule" plus (ii) "…it would be virtually impossible for anyone to win an individual medal without a training history comparable with that of today's elite performers, nearly all of whom started very early" (2007, p. 119).

The deliberate practice hypothesis was originally formulated in the field of music. It has then been applied to many domains of expertise, including sports (Hyllegard & Yamamoto, 2007), chess (Gobet, Fernand & Campitelli, 2007) and mathematics teaching (Han & Paine, 2010). Most domains show a correlation between the amount of practice and the level of expertise (Baker, J., Horton, Robertson-Wilson, & Wall, 2003; Ford & Williams, 2012). However, the amount of variance accounted for differs considerably between domains (Hambrick et al., 2014) with for example 26% accounted for in chess and only 4% accounted for in education. There is also substantial variability of practice, even between individuals performing at the same level (Gobet & Campitelli, 2007; Hambrick et al., 2014).

Research into deliberate practice has been particularly extensive in sports, where the correlation between the amount of domain-specific practice and skill level has been an area of debate. Many researchers have shown this correlation to be a robust phenomenon. For example, in soccer, over a career period of 18 years, international players accumulated more deliberate practice (*M* = 9,332 hr.) than national players (*M* = 7,449 hr.) and provincial players (*M* = 5,079 hr.) (Helsen et al., 1998). However, differences between sports have also been identified. Compared to soccer, Baker, Côté, and Abernethy (2003a) reported shorter periods to excellence in basketball (*M* = 5,908 hr. of deliberate practice), netball (*M* = 2,260 hr.) and field hockey (*M* = 3,583 hr.). Furthermore, Baker, Côté, and Deakin (2005) reported that the period to excellence is fairly long in Ultra Distance Triathlon, requiring a mean of 12,558 hr., with considerable variability (range: from 8,004 hr. to 19,630 hr.). This result is not totally unexpected, as high levels of specialization are required in three different activities: swimming (*M* = 3,472 hr.), cycling (*M* = 5,039 hr.) and running (*M* = 3,457 hr.), although results do identify the likely performance benefits of practice of the other two sports (i.e., conditioning achieved by swimming and cycling may be beneficial in running). Analyzing the careers of 15 Olympic sprint champions and of the 20 fastest male American sprinters, Lombardo and Deaner (2014) found that these athletes were considered as exceptional already before starting training and that they reached world-class level in fewer than 10 years of deliberate practice (a median of 3 years for the Olympic champions, and 7.5 years for the fastest American sprinters). Ericsson (2006) acknowledges that "people are able to reach world-class levels in fewer than ten years in activities that lack a history of organized international competition" (p. 692). However, as noted by Hambrick, Burgoyne, Macnamara, and Ullén (2018), activities such as running and chess, where individuals have reached expert level in much less than 10 years, do enjoy a long history of organized international competition.

In contrast, research comparing the sporting history of elite athletes across sports has focused on prior sport engagement that cast doubts on the robustness of the relationship between domain-specific practice and skill. Studies comparing medalist and non-medalist elite performers found that medalists were more likely to have engaged in coach-led practice and competitive opportunities not associated with their medal winning sport; in addition, they started to engage in the medal-winning activity later than non-medalists (Güllich & Emrich, 2014; Güllich, 2017). This demonstrates that, when sub-elite levels of expertise are compared with elite levels, the monotonic relationship between practice and skill is not confirmed.

Williams and Ericsson (2008) note that the sports domain has particular difficulties in identifying and measuring particular components of deliberate practice, leading to loose definitions of the term and thus variable estimates of the amount of deliberate practice needed to reach expertise. Furthermore, Ericsson et al.'s (1993) data rely upon professional musicians with a mean age of 50.5 years recalling what practice they did at ten years of age, thus leading to the likelihood of recall bias. Contrary to theory, deliberate practice activities have been found enjoyable in several sports (Helsen et al., 1998; Hodges & Starkes, 1996). Not only individual, but also team practice is essential in many sports (Helsen et al., 1998; Ward, P., Hodges, N.J., Williams, A.M. & Starkes, J., 2007). In addition, several athletes use techniques such as mental concentration and imagery in addition to deliberate practice (Starkes, Deakin, Allard, Hodges, & Hayes, 1996).

As noted above, deliberate practice predicts that the best way to reach excellence is through early specialization, as this optimizes the number of hours engaged practicing. However, while some studies support early specialization in sports such as soccer and rhythmic gymnastics (Law et al., 2007; Ward, P., Hodges, N.J., Williams, A.M. & Starkes, J., 2007) others support the opposite approach, namely early diversification (Barynina, I.I., & Vaitsekhovskii, S.M., 1992; Carlson, 1997; Güllich, 2014; Güllich, 2018bb) in sports such as swimming, baseball, tennis, field hockey, netball, and basketball.

The aim of this article is to understand the role played by the demands of the sport chosen, including its relation to motor skill and energy pathway, the role of early practice and the role of individual versus team practice in attaining top-level athletic performance. To do so, selection consisted of participants selected to represent Team GB in the London 2012 Olympics in athletics. The domain of track and field athletics offers a range of events where features such as motor skill and the energy pathway utilized are clearly determined. In particular, the researched attempted to ascertain whether 10 years of deliberate practice to expertise, early specialization (domain-specific practice), and individual practice (compared with team practice) are necessary conditions for acquiring expertise within the domain of track and field athletics. The hypothesis was that the period to excellence in track and field athletics is affected by the following variables: (a) motor skill, classified using Magill's one dimensional system (Magill, 2001) and operationalized in the study as track (gross, continuous, open), field (gross, discrete, open), and multi-events (gross, continuous/discrete, open) (International Olympic Committee, 2012), (b) the energy pathway (dominant aerobic or dominant anaerobic) (Kenney, Wilmore, & Costill, 2012) using Fox, Bowers, and Foss's (1993) sports classification; and (c) previous sporting experience with three aspects: diversification vs. specialization, energy pathway (dominant anaerobic vs. dominant aerobic), and sport type (individual vs. team).

5.2 Method.

5.2.1 Participants.

The sample consisted of all participants in athletics selected for Team GB in the London 2012 Olympics ($N = 72$). Participants were 44 men and 28 women aged 18 to 32 years (Men: $M = 22.8$, $SD = 3.1$; Women: $M = 23.6$, $SD = 3.3$). Multi-event athletes ($n = 4$) are not included, nor were two women field athletes due to the unavailability of data on their deliberate practice starting point. Table 11 displays the numbers of Great Britain track and field medal winners at London 2012 Olympics.

The sample was partitioned in four ways: (a) type of current sport, sub-divided into track-running events ($n = 57$) and field events ($n = 15$); (b) energy pathway of current sport, sub-divided into dominant aerobic ($n = 21$) and dominant anaerobic ($n = 51$); (c) energy pathway of previous sports, sub-divided into dominant aerobic ($n =$

21), equal contribution from aerobic and anaerobic pathways (n = 19), and no previous sport (n = 32); and (d) composition of previous sports: team sports (n = 25), individual sports (n = 15), and no previous sport (n = 32).

Table 11. Great Britain medal winners at London 2012 Olympics.

Team GB London 2012 Track and Field results			
Medal	Gold	Silver	Bronze
Quantity	4	1	1

5.2.2 Data Collection.

All Team GB track and field athletes selected for the London 2012 Olympics. In the literature, this is characterized as a hard-to-reach population (King, O'Rourke, & DeLongis, 2014; Rhodes, Bowie, & Hergenrather, 2003). The following online sources were drawn upon. First, the search engine Google (https://www.google.co.uk/search) was used as a general source of information. Second, the BBC (B.B.C., n.d.) media website provided the following information: (a) identification of participants, (b) date of birth, and (c) some social networking information where further biographical data may be sought such as Twitter, Facebook, and personal website addresses. Third, the Telegraph (Telegraph, n.d.) newspaper website provided basic biographical information such as when the athlete started in their sport, whether they had competed in other sports, and when they joined a club and focused on their sport. Fourth, the search for further biographical information was enhanced by a Google search based on athletes' names and identifying their personal website, which often linked to personal agents and promotional companies. Finally, the website Power of 10 (Power of, n.d.), which is the official statistical tool of UK Athletics. This site offers a complete list of registered performances in UK meetings, plus notable participations in national meetings and selections for international meetings. In addition, information was sought via personal management companies and agents, who often represented more than one Team GB athlete. This involved simple questions for them to obtain answers from the athlete, such as (a) When did you start to focus on your sport? (b) At what age were you coached for your sport? (c) Did you train for any other sport prior to focusing on your main sport? If yes, which sport?

5.2.3 Measures.

As seen above, the period to excellence from novice to expert is hypothesized to be at least 10 years; to operationalize this variable, the difference between the finishing point (expert) and starting point (novice), as suggested by Ericsson et al. (1993) was utilized. All durations < 10 years were considered in disagreement with the deliberate practice framework. All durations ≥ 10 years were considered in agreement with the deliberate practice framework.

The start of deliberate practice was operationalized in accordance with Ericsson et al. (1993). The point at which athletes initiated a motivated attempt to enhance performance, using the criteria specified by Ericsson et al., such as joining a club, being coached, or engaging in competition within the sport of choice. The end of the period to excellence coincides with the mastery of existing techniques and knowledge, which is often exemplified by the individual earning an income from performances within the domain. In the sample, the finishing point was operationalized as the first selection for an international senior outdoor athletic championship (for full detailed results from Team GB 2012, see table 12). The term "senior" is defined by UK Athletics as representing athletes who are 20 years or over on the 31st December in the year of competition; under-17 men and women (school years 10 and 11) may compete against seniors in events less than 3000 meters (see UK Athletics Rule Book, http://uka.org.uk/competitions/rules/).

The first author collected the athletes' date of birth, starting point of deliberate practice, previous sporting experience, and date of acquiring expertise. The second author independently coded the starting point of deliberate practice and the date of acquiring expertise. The two coders were in agreement in 91% of the cases. The points of disagreement (3 starting dates and 10 finishing points) were all resolved through discussion.

Table 12. Championships in which expertise was first achieved.

First competitive senior championships				
Championships	World	Commonwealth	Olympics	European
Quantity	22	13	21	16

Two types of sports were identified (International Olympic Committee, 2012; Magill, 2001). *Track events* consisted of gross, continuous, and open skills; and *field events* consisted of gross, discrete, and open skills. The track, marathon, and race-walking athletes represented the track group, and the jumps and throws athletes represented the field group. In addition, in line with the sport-science literature (Kenney et al., 2012), two energy pathways were selected based on the dominant use of either the *anaerobic pathway* or the *aerobic pathway* in performance (Fox et al., 1993). The dominant anaerobic group consisted of those athletes where performance energy was obtained from two systems, either the anaerobic alactic (ATP-CP) or the anaerobic lactic (Bompa & Carrera, 2005) The track athletes from sprints up to 800 meters and field event athletes represented this group (Fox et al., 1993). The dominant aerobic group consisted of those athletes where the main determinant of performance was aerobic energy (Bompa & Carrera, 2005) **;** this group was represented by the events further than 800 meters (Fox et al., 1993).

The question on previous sport participation made it possible to pinpoint the sports in which the participant trained prior to focusing on their Olympic event. However, the extent to which this was deliberate practice could not be ascertained. The influence of previous sport involvement was studied from two perspectives. The energy pathway perspective subdivided sports into (a) dominant aerobic, (b) combination of both aerobic and anaerobic (no participants identified exclusively a dominant anaerobic sport) and (c) no previous sporting experience. The sports composition perspective subdivided sports into (a) team, (b) individual performance, and (c) no previous sporting experience.

5.3 Results.

5.3.1 Descriptive statistics.

Table 13 displays the descriptive statistics of the sample, and figure 15 shows the frequency histogram of the period to excellence.

Table 13. *Descriptive statistics of the period to excellence (in years).*

	N	Minimum	Maximum	Mean	Std. Deviation	Median
Period to Excellence	72	0.67	13.30	7.21	3.20	7.20
Starting Age	72	8.01	26.02	15.92	2.92	16.01
Expertise Age	72	18.34	31.99	23.33	3.27	22.59

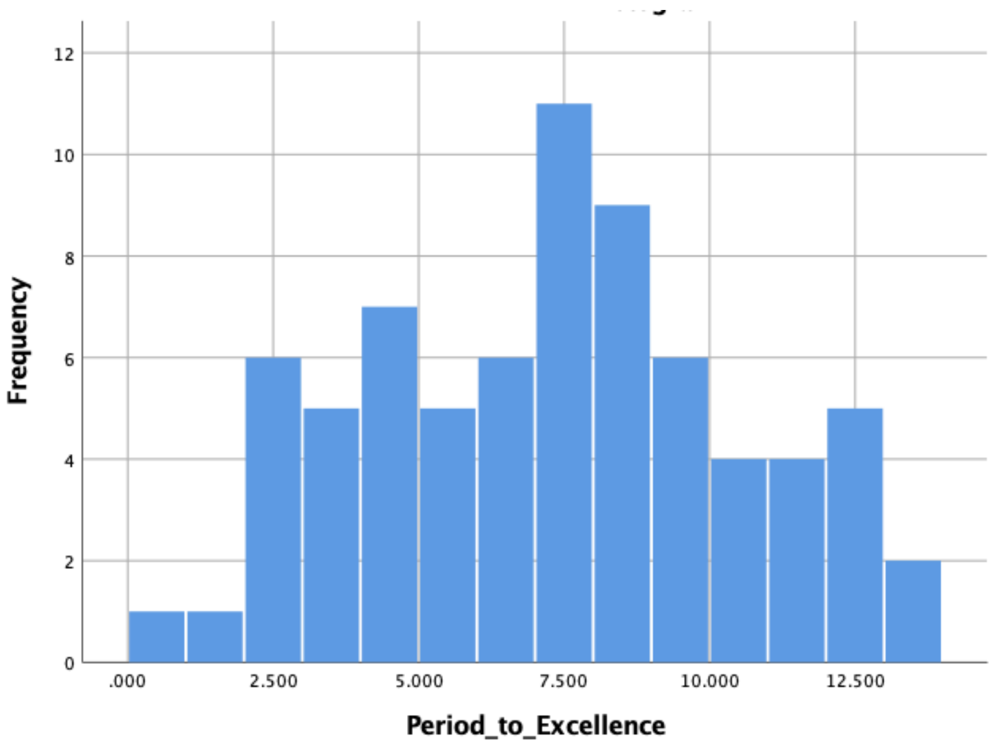


Figure 15. Frequency histogram of period to excellence.

5.3.2 The Period to Excellence Measured from the Entire Sample (*n* = 72).

It took on average 7.20 years (SD = 3.20) to become an expert. There was no reliable difference between female (M = 7.41 years, SD = 3.13, n = 28) and male athletes (M = 7.08, SD = 3.27, n = 44), F (1, 70) = 0.18, p = .676, η_p^2 = .003. Fifty-seven athletes (i.e., 79.2% of the sample) needed less than 10 years to reach expert level. A t test revealed a statistically significant difference between the observed mean period to excellence and the hypothesized 10 years, t (71) = -7.41, p < .001, 95% CI of mean difference [-3.54, -2.04].

5.3.3 The Period to Excellence and its Association with Event Type.

The mean period to excellence for track athletes was 7.43 years (*SD* = 3.37, *n* = 57, range = 0.67–13.30 years). Forty-three athletes reached expertise before 10 years, representing 75.4% of all track athletes irrespective of event. The mean period to excellence for field athletes was 6.36 years (*SD* = 2.38, *n* = 15, range = 1.82–10.49 years). Fourteen athletes reached expertise before 10 years, representing 93.3% of all field athletes irrespective of event. The difference between track athletes and field athletes (1.07 years) was not statistically significant, $F\,(1, 70) = 1.33$, $p = .253$, $\eta_p^2 = .019$.

5.3.4 The period to Excellence and Components Associated with the Energy Pathway.

The mean period to excellence of the dominant anaerobic group was 6.15 years (*SD* = 2.84, *n* = 51, range = 0.67–12.72 years). Forty-seven athletes reached expertise before 10 years, representing of 92.1% of all athletes using predominantly the anaerobic system, irrespective of event. A t test revealed a statistically significant difference between period to excellence and the hypothesized 10 years, $t\,(50) = -9.70$, $p < .001$. The mean period to excellence of the dominant aerobic group was 9.78 years (*SD* = 2.52, *n* = 21, range = 3.69–13.30 years). A t test revealed that the observed mean period to excellence did not differ significantly from the hypothesized 10 years, $t\,(20) = -0.4$, $p > .05$. Ten athletes reached expertise before 10 years, representing 47.6% of all athletes using predominantly the aerobic system, irrespective of event. The dominant anaerobic group was 3.63 years faster than the dominant aerobic group to reach expert level, a difference that is statistically significant, F (1, 70) = 25.97, $p < .001$, $\eta_p^2 = .27$ (see figure 16).

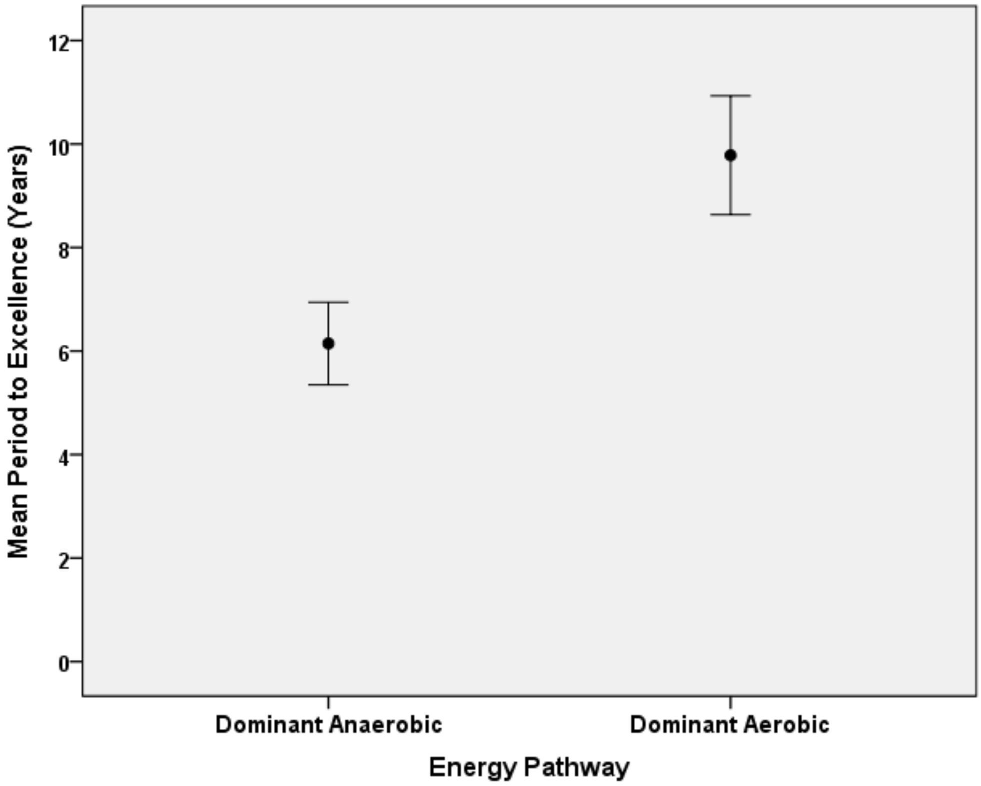


Figure 16. Period to excellence as a function of energy pathway; errors bars indicate 95% confidence intervals.

5.3.5 The Period to Excellence and Previous Sporting Experience.

Investigating the influence of an athlete's previous sporting experience showed that those who did not specialize early (n = 40) were significantly faster in acquiring expertise in a new sport than those who specialized early (n = 32), 6.27 ± 2.78 vs. 8.38 ± 3.34 years, F (1,70) = 8.53, p = .005, $\eta_p^2 = .109$**.** This suggests a contribution to performance from other sports and is inconsistent with the hypothesis that practice should be deliberate early on. However, even those who specialized early achieved expertise significantly quicker than 10 years, *t (*31) = -2.74, *p* = .01, 95% CI of mean difference [-2.82, -0.41].

5.3.6 The period to Excellence and the Energy Pathway with Reference to Previous Sporting Experience.

In this and the following analysis, only those athletes who engaged in previous sports were considered. The first group (the dominant anaerobic group) consisted of those athletes who had participated in previous sports such as cricket, gymnastics, and squash. Its mean period to excellence was 5.99 years (*SD* = 2.34, *n* = 21). The second group combined anaerobic and aerobic group, where the energy systems were both engaged, and was represented by football, rugby, and ice hockey. Its mean period to excellence was 6.27 years (*SD* = 2.78, *n* = 19). An analysis of variance showed no significant difference between these two groups, *F* (1, 38) = 0.445, *ns*, *p* = .51, η_p^2 = .012.

5.3.7 The period to Excellence and Previous Sporting Experience (Team vs. Individual).

The team group consisted of those athletes who had previously participated in previous sports such as cricket, football, and hockey. The period to excellence was 6.22 years (*SD* = 3.14, *n* = 25). The individual group consisted of those athletes who had previously participated in previous sports such as swimming, athletics, and tennis. The mean period to excellence was 6.34 years (*SD* = 2.14, *n* = 15). An analysis of variance found no significant difference between the two groups, *F* (1,38) = .019*, p* = .892, η_p^2 = .000.

5.4 Discussion.

The framework of deliberate practice (Ericsson et al., 1993; Ericsson, 2016) which emphasizes the role of intensive goal-directed practice in becoming an expert whilst denying the contributions of talent (other than size and personality) and type of skill, has been highly influential in the last two decades. Previous investigators have utilized different roles within a sport to assess expertise, studying both single sports (Ford & Williams, 2008; Güllich, 2014; Güllich, 2018a; Helsen et al., 2000) and multiple sports (Baker et al., 2003; Güllich & Emrich, 2014; Güllich, 2017; Memmert, Baker, & Bertsch, 2010). Thus, typically, the speed in acquiring (Ford & Williams, 2008; Güllich, 2014; Güllich, 2018; Helsen et al., 2000) expertise in soccer is represented by a mean value of goalkeepers and outfield players, wingers, and defenders. However, the individual skill components that make up overall sports performance have largely been ignored. Particularly, investigators have focused on domain-specific enquiry to the detriment of understanding those talents and general skills constituents that comprise individual differences. An exception is offered by Güllich and colleagues, who have made significant advances in understanding the interaction between previous sports training and domain practice in elite performance, critically concluding that it is organized practice in other sports, and not the main sport, that specifically contributes to elite performance (Güllich, 2014; Güllich & Emrich, 2014; Güllich, 2017; Güllich, 2018a; Güllich, 2018b). The current research has concentrated on the characteristics of the current sport event (type of event and dominant energy pathway) and the characteristics of the previous sports (dominant energy pathway and individual versus team practice), affording an opportunity for investigating particular influences in acquiring specific athletic expertise. The result confirms at the expert phase, the energy pathway is significant in the speed of acquiring expertise.

The methodology utilized by Ericsson et al. (1993)identified the starting and finishing point for the measures of the period to excellence. The criteria of joining a club, being coached, and performing competitively within a sport-specific domain define different potential starting points and potentially can produce conflicting results. The concept of performing competitively is introduced as a catalyst for further competition and a precursor for joining a club or seeking a coach; the contention was that competitive performance would normally satisfy these criteria. Identifying each measure and utilized the earliest date identified. The finishing point of expertise was defined as competition in a senior international outdoor championship; note that junior competitions were intentionally omitted and senior indoor championships. International senior championships have strict selection criteria, which are usually based on two factors: (a) winning a national championship or (b) achieving a qualifying mark (e.g., distance, time). If a junior achieves these standards and has the requisite minimum age, then they can compete at a senior level subject to several limitations, as there are age group differences (e.g., field implements are heavier, hurdles are higher, and juniors are not allowed to compete against seniors over 3000 meters or longer). Furthermore, indoor championships tend not to follow such exacting qualification standards as outdoor championships. In total, the strict criteria mean that it is possible that the actual finishing point of expertise is shorter than the chosen value. The consequence would be that the period to excellence is further reduced, thus strengthening the conclusions.

I had considered using just participants' who had achieved medal status as achieving expertise. This methodology has been previously used previously in team sports (Barreiros, Côté, & Fonseca, 2013; Güllich, 2017) as well as in individual (Barreiros et al., 2013; Güllich, 2017; Moesch, Elbe, Hauge, & Wikman, 2011). However, the overall objective of the research was to investigate, across a wide range of events, if the energy pathway influenced the speed at which expertise was acquired. Although would expect expertise to be achieved before elite medal status is acquired, and thus limiting the research to medalists was not necessary.

Using data from Team GB at the London Olympics in 2012, the current study tested a key prediction of the deliberate-practice framework – that it takes 10 years of deliberate practice to become an expert in any domain – and examined its boundary conditions. Consistent with Gobet and Ereku (2014), Baker et al. (2003a) and others, this prediction was not supported by the data, as the average number of deliberate-practice years in the sample was 7.20 years (SD = 3.20). Importantly, four fifths of the athletes sampled required less than 10 years. Although there was a tendency for track athletes (7.43 years) who utilize gross, continuous, and open skills to take longer than field athletes (6.36 years) using gross, discrete, and open skills, sport type was not significantly associated with the number of years to reach expertise. By contrast, energy pathway was associated with the mean period to excellence, with athletes in the dominant anaerobic group (6.15 years) being significantly quicker than athletes in the dominant aerobic group (9.78 years). Finally, the presence of a previous sport was reliably associated with the period to excellence, with athletes who specialized early taking longer (8.38 years) than athletes who did not specialize early (6.27 years). However, within the athletes who had previously engaged in different sports, neither the practice of team or individual sports nor the energy pathways of the previous sport(s) predicted the period to excellence.

As noted earlier, previous research had noted specific exceptions to the "10-year rule", for example in chess (Gobet & Ereku, 2014) and team ball sport (Baker et al., 2003). However, the data indicate systematic violations across a broad spectrum of track and field events. The current research suggests that the shorter dominant anaerobic events result in a reduced time to excellence compared to longer dominant aerobic events. This is in line with previous research (Hodges et al., 2004) showing that practice results were event specific in swimming. Furthermore, the dominant anaerobic group consisted of many field athletes whose mean period to excellence was shorter than that in the dominant aerobic group. Suggesting that the considerable time for physiological adaptations to occur in aerobic capacity inevitably leads to a longer period to acquire expertise.

The results also shed light on the question of early specialization vs. diversification in sports, which has previously produced contradictory results (e.g., Gobet, 2015). The data clearly support the importance of doing a variety of sports before specializing on the target sport. But what is the motivation for individuals to practice multiple sports? The results predominantly identify the teenage years as the initial period of acquiring expertise; variety is important and I hypothesize that at this period it is the enjoyment of practice that leads to multiple sports activity (Gould & Petlickhoff, 1988). Both are contrary to Ericsson et al.'s (1993) claims that deliberate practice is not enjoyable, and that diversification does not contribute to expertise.

5.4.1 Limitations.

The study has a number of limitations. As is common with studies on world-class experts, the sample size is somewhat limited. In addition, deliberate practice was not operationalized in the usual way, using retrospective protocols. In this respect, note that the reliability of retrospective verbal protocol has been criticized in general (Ericsson & Simon, 1993) and in particular within the context of researching the topic of deliberate practice. For example, Macnamara, Hambrick, and Oswald (2014) note that the exact method of collecting measures of deliberate practice leads to substantial differences: with retrospective interviews, 20% of the variance in performance is explained; with retrospective questionnaires, 12% of the variance is explained; finally, with a log method, which presumably offers the best estimate as the amount of practice is recorded concurrently, only 5% of the variance is accounted for. Furthermore, to overcame potential recall bias, online data collection methods were used which are considered at least as good as in-person data (Casler et al., 2013; Gosling et al., 2007; Vazire & Gosling, 2004). Thus, the method, while not perfect, reflects recommended methodology in hard-to-reach populations such as elite athletes.

The measure of the period to excellence calls for two comments. First, the cut-off chosen for achieving expertise – first selection for a senior outdoor international championship – was likely to extend this period. Importantly, by omitting junior and senior indoor championships, resulted in the assessment of expertise made by an independent, third party (the UK Athletics). Second, estimates of the age at which expertise was started has limitations, particularly with respect to the media data. For example, practice activities before the start year may have contributed towards expertise, resulting in longer period to expertise than calculated. However, the objective was to rigorously follow Ericsson et al. (1993) to ensure that comparisons between deliberate practice and period to excellence are valid. Although other starting points are possible – e.g., prior coaching in a sport different from that where expert performance was achieved (Güllich, 2014) –considering it best practice for comparative purposes to utilize the definition provided by Ericsson et al. (1993). In addition, and importantly, even though the methodology might include some time that is not optimal and thus might overestimate the period to excellence, the conclusions are not affected: if there is overestimation, the true amount of deliberate practice necessary for reaching expertise is even less than reported.

Finally, the way data was collected did not enable us to calculate a mean period of daily practice and compare it with the often-quoted 10,000 hours of deliberate practice applied over 10 years (Ericsson et al., 1993; Ericsson et al., 2007; Ericsson, 2016; Gladwell, 2009). The period to excellence can be directly compared with the overall practice period (10 years) that takes into account practice, rest, recuperation, and rehabilitation after injury but not the hourly measures of practice. The application of daily practice to achieve expertise is influenced by individual differences and the many different periods to expertise reported in sport are most likely a representation of sports differences (Baker et al., 2003; Baker et al., 2005; Helsen et al., 1998; Hoare & Warr, 2000; Hodges & Starkes, 1996; Lombardo & Deaner, 2014; Ward, P., Hodges, N.J., Williams, A.M. & Starkes, J., 2007).

5.5 Conclusion.

Altogether, the results add to a growing body of evidence questioning the deliberate practice framework (Hambrick et al., 2014; Macnamara et al., 2014). Result identifies the energy pathway is significant in the speed of acquiring expertise and the expert phase. The amount of deliberate practice necessary for becoming an expert varies considerably between fields, and the fact that, in some sports, individuals can reach expert level in a couple of years, as shown in the data, suggests that other factors are important beyond domain-specific deliberate practice.

The deliberate practice hypothesis suggests that talent and previously acquired general skill do not directly contribute to the acquisition of expertise, which can instead be attained only after 10 years of deliberate, motivated practice. The results suggest that expertise can be attained quicker than 10 years and that trying multiple sports before specializing in a new sport has a positive influence on the speed of acquiring expertise.

6 Chapter 6 Discussion.

This research has highlighted the influence of talent in the speed of acquiring motor expertise and has shown that the selected measures of talent are associated with the stage of skill acquisition. Results have shown that 1) at the novice phase, working memory is significantly associated to performance in a hockey task; 2) at the intermediate phase, detection (measures of power output and cadence) is superior to traditional TID (race result rank), and 3) at the expert phase, the energy pathway is significant in the speed of acquiring expertise.

Sport science is developed by understanding what experts do and applying similar techniques to those with less experience in the expectation that the same methodology will improve novices' performance. This is defined as a *top-down* approach and is the prevalent methodology of developing skill acquisition. Conversely, a *bottom-up* approach which consists of matching talents with sports expertise has not been popular. However, when the latter approach has been applied in sport, results have been positive – for example physiological measures in cycling chapter 4 and anthropometric measures in rowing (Rees et al., 2016). This research emphasises the potential to move beyond the prevalent methodology of developing skill acquisition by a *top-down* approach: assessing the contribution of talent to the acquisition of expertise will be instrumental in understanding how performance gains can be achieved.

This discussion chapter will highlight the issues that surround the measurement of the effects of talent in performance and how it fits within the theories of expertise and talent identification. It will also assess the deliberate practice hypothesis and its use in the sports domain. Particular emphasis will be placed upon mental abilities and how these influence motor skill acquisition.

6.1 A model of the contributions of talent and practice as determinants of sport performance?

The current research indicates that an adequate theory of expertise requires both talent and practice – these form a congruous partnership, not a dichotomy (Ackerman, 2014; Gobet, 2013). In this section, I will outline a framework for extending Gobet's (2013) model of expertise to sport by integrating results from the thesis and previous research.

Talents are associated with critical periods when expertise is acquired at an enhanced speed (Chassy & Gobet, 2010; Tucker & Collins, 2012). Indeed, chapter 4 and 5 of these theses provide evidence for the speed of acquisition acceleration due to these factors.

Gobet's (2013) model of expertise uses interactions between practice, intelligence (an innate factor), and the environment to explain how performance develops over time. The current research examined the role of several innate factors, such as mental abilities (Chapter 3), physiological performance (Chapter 4), and energy output (Chapter 5). Therefore, the question is how these factors might be included within this model and how we can represent differences in their importance that may occur across the three phases of experience (novice, intermediate, and expert). This research investigated the contribution of specific factors at particular phases but did not look at other possible combinations (example, combining mental abilities and expert performers), but previous research suggests that they are likely to differ in importance at differing levels of expertise (see section 2.1 of the current thesis). It is proposed that the three phases of achievement are added to Gobet's model to represent changes in expertise (see figure 17). This proposed model of sporting expertise introduces a range of natural talents generally identified by physiological, psychological, and anthropometric measures. These are not specifically delineated, as further research is required to provide a more comprehensive list, and to determine their significance across expertise levels.

This thesis identifies three factors underlying sporting performance, working memory, physical output (e.g., power, anaerobic capacity, etc.) and respiration of oxygen. Each factor is associated with the performance phases (novice, intermediate and expert), so working memory is associated with novice performance, but its relationship with intermediate or expert is unknown. The use of each factor outside the performance phases requires further research. The schematic (see Figure 17), suggesting that these can be applied across performance phases and many types of sports, though their importance may vary. Hence, in cycling, it is proposed that it can be used for training in sport; and some events could be influenced by power output and aerobic capacity (Bompa & Carrera, 2005).. Therefore, at the intermediate phase, sports TID can identify the event where these talent motor abilities influence performance. Although the result may be different if applied to the novice or expert phase. Indeed, in gaining sports expertise, the phase of motor skill acquisition is consequential.

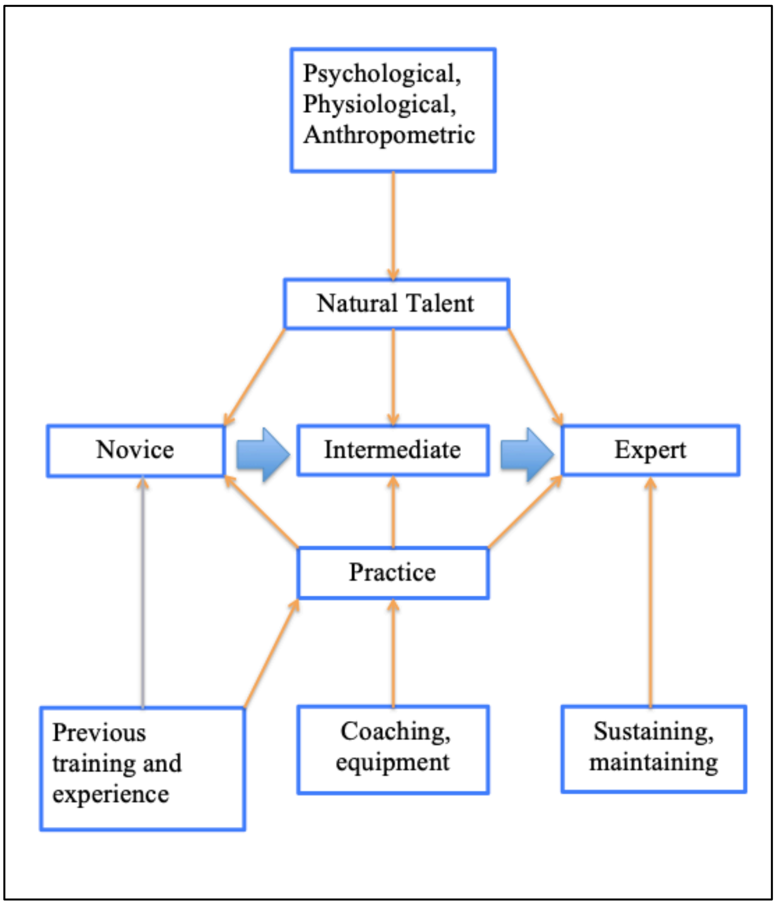


Figure 17. A schematic representation of a model of sporting expertise based on Gobet (2013) complex model of expertise.

6.1.1 Applying a model of sporting expertise to talent identification.

The results indicate that individual variability in innate abilities influences sports performance, but how might this effect the potential to influence talent identification (TID). Currently the overwhelmingly main selection criteria for TID are performance-based (U.K. Sport, n.d.(a)), but natural talent has had some influence in TID; for example, UK sport *tall and talented* selection via anthropometric measurements alongside general sports performance measures (U.K. Sport, n.d.(b)), and *power 2 podium* selection using physiological measures (U.K. Sport, n.d.(c)). Therefore, although there has been a gradual introduction of identifying specific aspects of talent, this has not been fully embraced across the whole range of potential talents but focused upon physical components that are sports specific.

Recent research has cast doubt on the rationale underpinning popular TID methodologies within sport. Research into the German high-performance system indicates a 44% turnover in athletes, with the youngest athletes frequently the first to leave (Faber et al., 2016; Güllich & Emrich, 2012) and later entrants often attaining better performance results (Güllich & Emrich, 2012). The current thesis found that, for cycling, athletes joining training programs at a younger age do not attain expertise as quickly as later entrances, although final performance was similar (see chapter 4). Importantly, if some athletes take longer to reach the same level of performance through training, this means that greater resources are expended on those individuals. Taken together, these results indicate using TID methods which identify potential and bring athletes into training programmes later may enable more athletes to be trained, with a greater retention rate and similar level of final performance.

Furthermore, elite success has been associated with general level of sporting activity rather than specifically the sport in which elite status is attained and so early specialization is not a requirement (Güllich, 2014). This is confirmed by the results of the current thesis (see chapters 4 and 5) showing that earlier specialization is not necessary to acquire expertise. These results further question the current TID doctrine that expertise results from selecting the athletes that are most proficient in a particular sport at a young age and applying task-specific coaching.

Indeed, studies of the German high-performance sports system found that a high proportion of squad members selected early left and were successfully replaced by older athletes who had developed more successfully outside the TID programme (Güllich & Emrich, 2012; Vaeyens et al., 2009). This result would be very difficult to explain within current TID systems (Collins & MacNamara, 2011). But the results are of interest and some researchers think that involving psychological methods may provide a solution (see the methodology section of chapter 3).

There is insufficient research to ascertain if the factors considered in this thesis would be successful in identifying those athletes who have developed outside the TID system but have the potential to attain elite performance levels. However, it can be concluded that these factors do contribute to performance, and that systematically identifying their contribution may help optimize the selection process. Nonetheless, the traditional approach can also identify individuals who have been performing at a high level in a particular sport. This aim is not to replace a traditional selection system but to broaden the selection possibilities for sports to best identify all the best potential competitors in a sport. Therefore, is it not time to re-evaluate the current TID proposition of selection and work out how best to incorporate talents? The integration of talent into a TID model would bring about a number of advantages associated with the psychological, physiological, and anthropometric domains of talent.

Chapter 3 showed that working memory directly effects sports performance, but higher cognitive functioning may be important for determining other relevant outcomes (Scharfen & Memmert, 2019; Voss et al., 2010). Specifically, greater cognitive skills may aid maintaining and developing expertise through their contribution to other mental abilities such as motivation, imagery, self-talk, goal setting, and anxiety control (Coffee & Rees, 2011; Gill, 2016; Hagan Jr et al., 2017; MacNamara et al., 2010; Pocock et al., 2019; Van Raalte et al., 2016).

Finally, physiological measures have already proved advantageous in British Cycling. The research presented in this thesis has shown that eight Olympic medals were won in Cycling at London 2012 by athletes selected by detection TID, i.e., measures of power and anaerobic capacity. In addition, anthropometric measures were used to select British Rowers for London 2012 and Rio 2016, with both Olympians and medalists (GB Rowing Team, 2009) being identified by this selection method. However, greater research in this area may identify more subtle factors. The current results have indicated the importance of the energy pathway demands of a particular sport effect in determining the period to excellence. As a consequence, it is possible to identify which sports would, or would not, benefit from selecting by physical potential in these areas. In this research, we tried to understand if novice participants can learn a skill based on their level on intelligence. We supplemented the motor abilities to include working memory, perceptual speed, and psychomotor skill. Our results indicated a significant correlation between working memory and most measures of hockey performance. Intelligence was significantly correlated with performance of the hockey score made past video intervention, but perceptual speed and psychomotor skill were not correlated. Whether similar results would have been found with tennis players or long jumpers is an open question. I assume that task complexity affects performance, but further research is required.

6.2 The importance of domain specific deliberate practice and talent.

The deliberate practice hypothesis (Ericsson et al., 1993) suggest a general theory of expertise: “we view elite performance as the product of a decade or more of maximal efforts to improve performance in a domain through an optimal distribution of deliberate practice” (p. 400). The original research domain for the deliberate practice hypothesis (Ericsson et al., 1993) was music, although it acquisition is often compared with sport performance and many sports citations noted. The focus of Ericsson et al.’s paper was placed firmly on the side of nurture, not nature. These authors spent an extraordinary amount of time utilising the terms 'talent', 'natural talent', 'talents', and 'talented' without ever defining them. Thus, the reader is required to interpret the meaning of these terms in the context of their argument. Ericsson et al. conclude that "although we are reluctant to accept individual differences in innate abilities (talent) and any important role of these differences in determining expert performance, we do not rule out the importance of individual differences in general" (p. 393). Thus, despite denying the influence of talent in the acquisition of expertise, they do not rule out individual differences, but also do not specify their nature or quantify their influence on performance. The current research clearly indicates that individual differences (talents) are an important contributory factor in acquiring expertise, which needs to be fully specified and considered.

Specifically, in Ericsson et al.'s (1993) paper, the section "Distinct Physical Characteristics of Elite Performers" (p. 394) largely focuses on physiological adaptations that become apparent as sport expertise is attained – adaptations with the heart, lungs, bones, and muscles, including the quantity of fast and slow twitch fibres. The physiological performance factors examined in chapters 4 and 5 were associated with a reduction the period of expertise. This is in line with previous results in other sports studies, for example see (Baker et al., 2005; Helsen et al., 1998; Helsen et al., 2000; Hodges et al., 2004; Lombardo & Deaner, 2014; Ward, P., Hodges, N.J., Williams, A.M. & Starkes, J., 2007).

6.2.1 Domain specific task.

A general theory of learning that suggests expertise is achievable across domains by 10,000 hrs of deliberate practice is fundamentally unwise (Ackerman, 2014). With research focusing on the minimum period needed to reach expertise, results across sports indicate faster periods in cycling chapter 4, and athletics chapter 5 (Lombardo & Deaner, 2014). Conversely, triathlon (Baker et al., 2005), and gymnastics (Law et al., 2007) exceed the minimum period. The considerable variability between sport requirements is suggested to be the reason for such differences (Ford et al., 2015). Therefore, if such variability is evident within the sports domain, then comparison across domains with substantial different requirements such as chess (Gobet & Campitelli, 2007) or nursing (Bathish et al., 2018) would be impractical.

In the current thesis, it was observed that when using a relatively objective criterion for expertise – competing at a national level – there was considerable variability in the period to attain this criterion across individuals within a sport and across sports. It follows that if expertise acquisition varies in these ways, then a contribution from non-practice factors is required and talent could explain this variability. In chapter 4, the results agreed with this argument: those selected by physical and skill-based tests had a faster period to expertise than those chosen by traditional selection based on rankings within sporting competitions. It is plausible to suggest that the use of other selection factors (e.g., psychological tests) for selection could have influenced these results further by refining candidate selection. The results from chapter 5 indicate the importance of respiratory physiology in speed of sports acquisition and suggest this should be an important selection criterion. Broadly, the differences in the speed of skill acquisition shown in chapters 3, 4 and 5 appear to relate to variations in factors that can be considered to be talent.

6.3 Measuring performance potential in a principled way.

In order to understand improvements in the hockey task, in chapter 3 a range of motor and mental abilities were measured using a strongly theoretical approach. In the early twentieth century, Spearman (1904) had proposed that significant MAMA relations will only be identified when both abilities have a same theoretical basis. Early researchers examining these factors found poor or non-significant results, with the included motor tests measuring strength and rapidity of voluntary movement (Bagley, 1901; Bolton, 1903; Wissler, 1901). Recent research included (a) taekwondo, where the technical procedure was interrogated for presence / absence of mistakes (Paunescu et al., 2013) and (b) football, such as passing accuracy and time (Ehmann et al., 2022), a significant correlation was found.

The hockey task was measured by an experienced coach using ACT-R (Anderson, 2007) In order to control the variability, a scoring chart, consisting of two potential measures (positional and techniques) was calculated, see appendix A. The two potential measures provided an opportunity for the hockey coach to self-check the scores by correlating these measures.

6.4 Performance measures, methodical and statistical issues.

Overall, previous research and the current thesis demonstrate that there are many contributory factors influencing performance outcomes, which in turn implies that sports selection models should really use principled multivariate analysis. A multiple regression analysis technique can be used to estimate performance from a range independent factor selected in a theoretically driven manner. Field (2009) commented that relevant results were unlikely if all potential predictors were entered, and suggested selection based on a sound theoretical basis and the results of past research. Furthermore, the order of entry into the model is vital, independent variables should be ranked based on importance using data and theory.

Although there are many psychometric measures in the current research (see chapter 3) it was ensured that multi-collinearity did not exist between these items. This research determined that performance could be estimated by a combination of working memory and procedural task knowledge.

To determine the factors that need to be considered for a particular sport, it is proposed that a taxonomy of factors should be constructed based on the existing literature and expert consultation. Prior research in sports performance has tended to focus on unitary factors and their influence on performance such as practice (Ericsson et al., 1993), intelligence (Paunescu et al., 2013), and the energy system (Staff et al., 2020). These can inform the selection of factors for multiple regression model for predicting expertise in a domain, which allows examination of their relative importance. This methodology can be utilized in talent identification to select individuals that produce optimal outcomes against the model.

It is important to make clear that these results are limited the conditions of the hockey experiment; the results of chapter 3 may not apply to tennis, for example, although a change in mental factors may produce similar result outcomes.

6.5 Performance gains vs. understanding elite expertise.

The paucity of research amongst sports scientists into similar questions asked in this PhD is perhaps surprising. It is possible that their interest lies in how to optimise any individual's performance rather than specifically identify individuals with the most potential. However, the demands of elite sports may differ from this more broad-based approach to performance improvement and this thesis suggests this should be reflected in the selection process. From this research on expertise, talent selection follows physiological measures in athletics, cycling (Staff et al., 2020; Staff et al., 2021), rowing (Rees et al., 2016) and psychometric measures (see chapter 3).

6.6 Limitations of research.

In understanding how talent affects sport performance progressions, the correlational approach to explain relationships is a well-used method for establishing associations (Field, 2009). However, correlation does not imply causation, although it can suggest a common link between factors that produce the effect (Gardner, 2000).

The results showed that using physiological performance has already clearly started, with genetic profiling becoming important, but the use of cognitive profiling offers interesting potential. Thus, it is important to follow up on the psychological research with empirical studies that will corroborate the results of this thesis. Although the questionable step in utilizing such associations is the extrapolation of the trend, for example will the application of resources always result in performance gains?

6.7 Future directions.

This research supports the initiation of the process of identifying and utilizing talents that contribute towards expertise in different domains. Future studies will need to identify innate factors that contribute to expertise and how they are influenced across the stages of expertise. Whilst novices may benefit from a high WM capacity, this may not be true by elite performance stages (though it may be a requirement to reach that stage).

A list of innate abilities and their influence in performance would provide guidance to researchers in assessing the utility of talent. The objective is to build up a domain holistic talent model for athlete selection (for example in football, combining working memory and spatial attention (Ehmann et al., 2021) that can influence research. Such research will contribute to a greater understanding of expertise. Finally, the introduction of gene research into the proposed model of expertise in this discussion sets out a futuristic position in understanding expertise, as currently we are still a long way from achieving that goal.

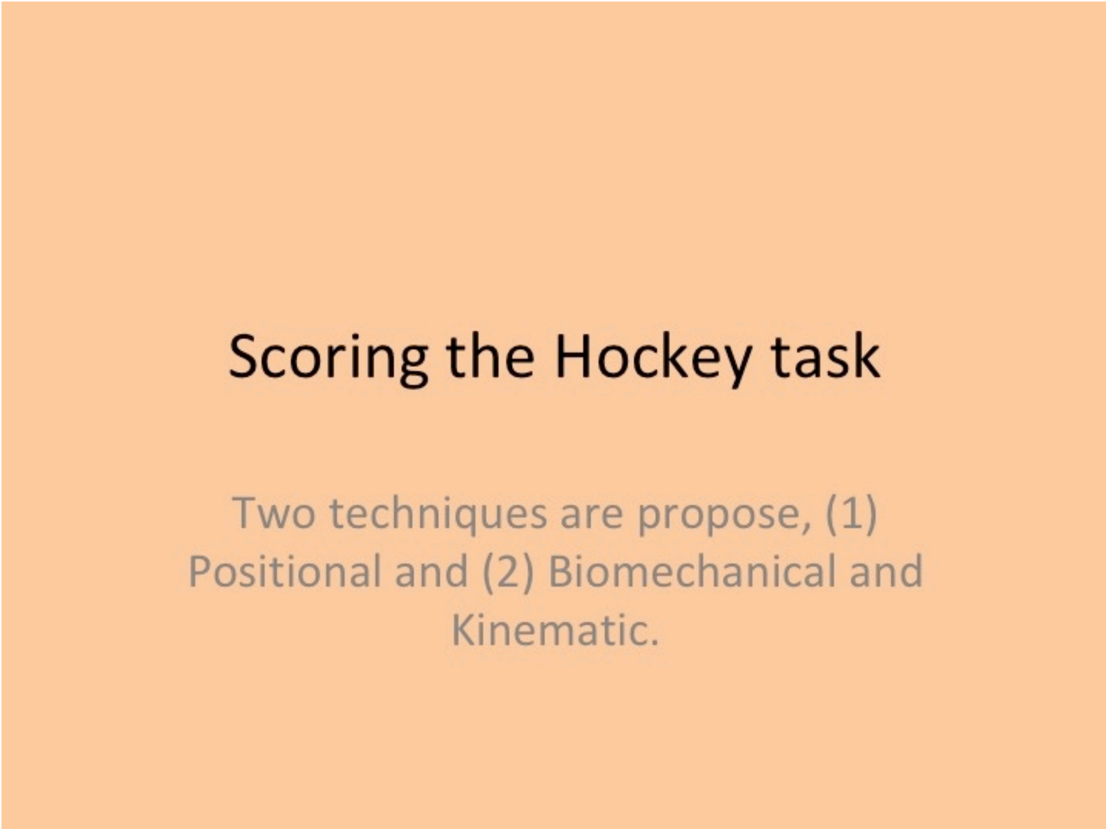
7 Conclusion.

Results indicated that talent affects performance at different levels of expertise. This occurs through factors such as working memory, power output and cadence, or energy pathway. However, the degree to which the contribution of factors varies across different stages of expertise and whether there are critical periods (as within the development literature) remains to be determined.

The findings suggest that working memory may predict early performance gains in sports and so could guide talent identification. However, a considerable amount of additional research is required to examine psychometric contributions to different sports and the principles that underlie this importance.

When understanding expertise, it is important to interpret all the factors that can contribute towards outcome. The results indicate that understanding talent will add further to expertise in sport.

Appendix A


Scoring the Hockey task
Two techniques are propose, (1) Positional and (2) Biomechanical and Kinematic.

The skill process.

1. Preparation, consisting of;
   a) Forward
   b) Stop
   c) Drag back
2. Throw
3. Control

Measuring basic positional technique.

- Preparation
  - P1. Hand position.
  - P2. Stick correct (flat edge).
  - P3. Body positioned to support forward movement, parallel to ball.
  - P4. Relative ball position.
  - P5. Stick face perpendicular to ball.
- Forward
  - F1. Forward movement, body or step.
- Stop
  - S1. Stick side.
- Drag back
  - B1. Backward movement body or step.
- Throw
  - T1. Retain hand position.
  - T2. Stick correct (flat edge).
  - T3. Sideways on.
  - T4. Ball between stance.
  - T5. Stick face parallel.
  - T6. Elevated ball.
  - T7. Drop the knee.
- Control
  - C1. Forward movement.
  - C2. Stick correct edge.
  - C3. Ball position.
  - C4. Ball Control.
- Outcome
  - O1. Score.

Calculations of positional score

- Preparation score (P) = P1+P2+P3+P4+P5+F1+S1+B1
- Throw score (T) = T1+T2+T3+T4+T5 +T6+T7
- Control score (C) = C1+C2+C3+C4

- Overall score (O) = P+T+C

Measuring variable biomechanical/ kinematic components.

- Preparation
  - P6. Ball distance from hurdle.
  - P7. Hand position.
  - P8. Angle of stick.
- Forward
  - F2. Speed of forward push.
  - F3. Distance pushed.
- Stop
  - S2. Stick angle.
- Drag back
  - B2. Speed of backward pull.
  - B3. Distance pulled.
- Throw
  - T8. Stick angle.
  - T9. Speed.
  - T10. Height above hurdle.

Calculations of technical score

- Preparation score (P) = P6+P7+P8+F2+F3+S2+B2+B3
- Throw score (T) = T8+T9+T10
- Overall score (O) = P+T

Technical scores

- TS5. Correct technique application.
- TS3. Progress towards the correct technique application but not fully achieved.
- TS2. A solution based rather than technically correct attempt.
- TS0. Unlikely to progress any further with the application of this technique.

Stages of measure.

1. First trial.
2. Prior to 1st video intervention.
3. Post 1st video intervention.
4. Intermediate trial (M5-M3)/2
5. Last successful lift trial.

Note: a trial is defined as an attempt to lift the ball over the hurdle. The ball passes the hurdle either lifted or not.

Preparation Stage

Subcomponent P1.
Hand position.

Note:
Top hand left bottom hand right, this will ensure the ball is pushed by the RH whilst LH guides the stick. When the RH is on top the LH performs a pull action that is resultant in reduced ball control.

TS5. Correct technique application.

Top hand left, bottom hand right.

TS3. Progress towards the correct technique application but not fully achieved.

N/A

TS2. A solution based rather than technically correct attempt.

Top hand right bottom hand left.

TS0. Unlikely to progress any further with the application of this technique.

Other techniques applied such as one handed.

Preparation Stage

Subcomponent P2. Stick correct (flat edge).

Note:
A hockey stick has a front (flat side) and a rounded (reverse side).

TS5. Correct technique application.

Flat side of stick.

TS3. Progress towards the correct technique application but not fully achieved.

N/A

TS2. A solution based rather than technically correct attempt.

N/A

TS0. Unlikely to progress any further with the application of this technique.

Reverse side of stick.

Preparation Stage

Subcomponent P3. Body positioned to support forward movement, parallel to ball.

Note:
It is possible to lift the ball by positioning the body behind the ball but this will impede further correct execution of other task components.

TS5. Correct technique application.

Parallel positioning allowing for ball directional movement.

TS3. Progress towards the correct technique application but not fully achieved.

N/A

TS2. . A solution based rather than technically correct attempt.

Behind the ball.

TS0. Unlikely to progress any further with the application of this technique.

Not parallel.

Preparation Stage

Subcomponent P4.
Relative ball position.

Note:
The position of the ball relative to the stance position initiates the required forward body movement and the achievement of optimal ball control.

TS5. Correct technique application.

Score as colour coded positions.

TS3. Progress towards the correct technique application but not fully achieved.

Score as colour coded positions.

TS2. A solution based rather than technically correct attempt.

Score as colour coded positions.

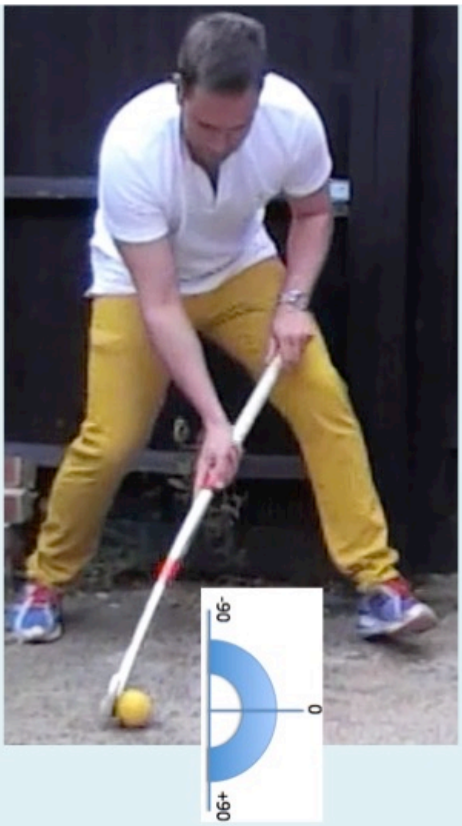
TS0. Unlikely to progress any further with the application of this technique.

Score as colour coded positions.

Preparation Stage

Subcomponent P5.
Stick face perpendicular to ball.

Note:
At the point of ball contacts the stick face should be perpendicular to the ball to facilitate parallel ball movement.



TS5. Correct technique application.

Parallel ball movement.

TS3. Progress towards the correct technique application but not fully achieved.

Range from +20 to -20 degrees off parallel.

TS2. A solution based rather than technically correct attempt.

N/A

TS0. Unlikely to progress any further with the application of this technique.

Range beyond +20 to -20 degrees off parallel.

Preparation Stage

Subcomponent P6. Distance of ball from the hurdle.

Note:
The optimal starting point is 1M from the hurdle give the objective is to place the ball on the spot. A greater distance involves the a greater applications of force leading to less control. A closer distance leads to a reduced likelihood of a successful lift phase due to reduced reverse ball speed.

TS5. Correct technique application.

Range between ≤ 1.2M ≥ .8M

TS3. Progress towards the correct technique application but not fully achieved.

Range > 1.2M

TS2. A solution based rather than technically correct attempt.

Range < .8M

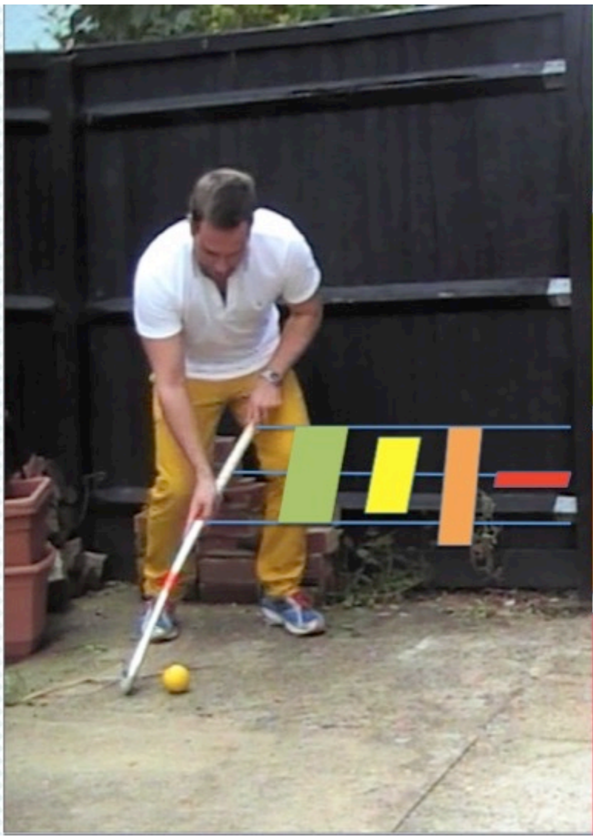
TS0. Unlikely to progress any further with the application of this technique.

N/A

Preparation Stage

Subcomponent P7. Hand position. Forefinger top, bottom thumb.

Note:
The grip placement allows optimal control at the lift stage. The narrower the grip reduces ball lifting sensitivity. A wider than optimal grip reduces ball control on the spot.



TS5. Correct technique application.

Grip placement, hands apart, 35-20mm.

TS3. Progress towards the correct technique application but not fully achieved.

Grip placement, hands apart, 19-15mm.

TS2. A solution based rather than technically correct attempt.

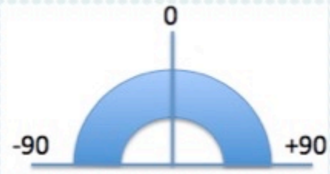
Grip placement, hands apart,> 36-45mm.

TS0. Unlikely to progress any further with the application of this technique.

Grip placement, hands together, < 15mm.

Preparation Stage

Subcomponent P8. Angle of stick.



Note:
The starting angle of the stick is associated to the relative level of ball control achieved.

TS5. Correct technique application.

Stick angle, forward between + 5 to +30 degrees.

TS3. Progress towards the correct technique application but not fully achieved.

Stick angle, forward > +30 degrees.

TS2. A solution based rather than technically correct attempt.

Stick angle, upright, + 0 to +4 degrees

TS0. Unlikely to progress any further with the application of this technique.

Stick angle, backward, negative angle.

Forward Stage

Subcomponent F1. Forward movement, body or step.

Note:
The step or sway movement enables the subject to position the stick to enable successful reverse action ball movement.

TS5. Correct technique application.

Step movement.

TS3. Progress towards the correct technique application but not fully achieved.

Exaggerated sway but no step.

TS2. A solution based rather than technically correct attempt.

Sway but not exaggerated.

TS0. Unlikely to progress any further with the application of this technique.

No movement.

Forward Stage

Subcomponent F2. Forward ball speed.

Note:
The forward ball speed is a control factor that initiates the step/swaying motion. The greater the speed the less control. The slower the speed the smaller the body movement.

TS5. Correct technique application.

≥ 2.00 ≤ 3.00 m/sec.

TS3. Progress towards the correct technique application but not fully achieved.

≤ 2.0 m/sec.

TS2. A solution based rather than technically correct attempt.

> 3.00 m/sec.

TS0. Unlikely to progress any further with the application of this technique.

N/A

Forward Stage

Subcomponent F3. Distance pushed.

Note:
The distance pushed is related to the amount of body movement achieved ultimately effecting the lift.

TS5. Correct technique application.

≥ .70 ≤ 1.00 m.

TS3. Progress towards the correct technique application but not fully achieved.

< .70 m

TS2. A solution based rather than technically correct attempt.

> 1.00 ≤ 1.20 m

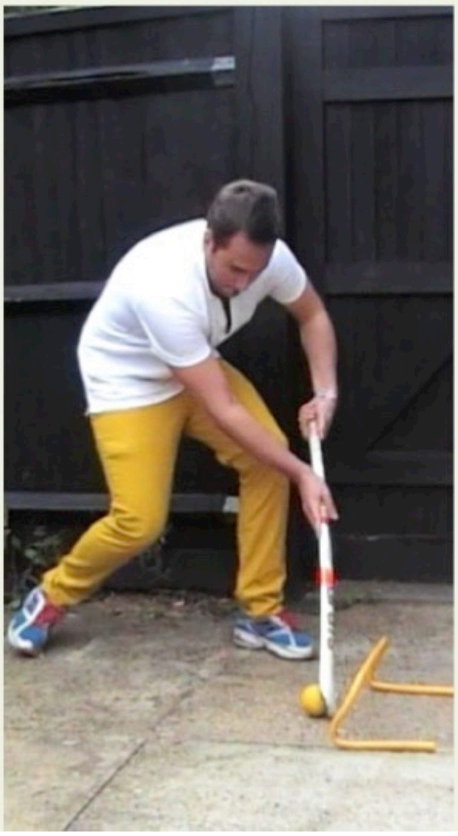
TS0. Unlikely to progress any further with the application of this technique.

≥ 1.20 or no movement.

Stop Stage

Subcomponent S1.
Stick side.

Note:
Stopping the ball with the flat side of the stick will increase the accuracy of the drag back



TS5. Correct technique application.

Flat face

TS3. Progress towards the correct technique application but not fully achieved.

N/A

TS2. A solution based rather than technically correct attempt.

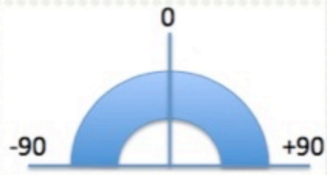
Reverse face.

TS0. Unlikely to progress any further with the application of this technique.

N/A

Stop Stage

Subcomponent
S2.Stick angle.



Note:
The accuracy of the drag back is dependent on the angle of the stick. This component is associated with flat or reverse stick

TS5. Correct technique application.

Range -10 to +10 degrees.

TS3. Progress towards the correct technique application but not fully achieved.

Range -11 to -30 degrees.

TS2. A solution based rather than technically correct attempt.

Range -30 degrees or greater.

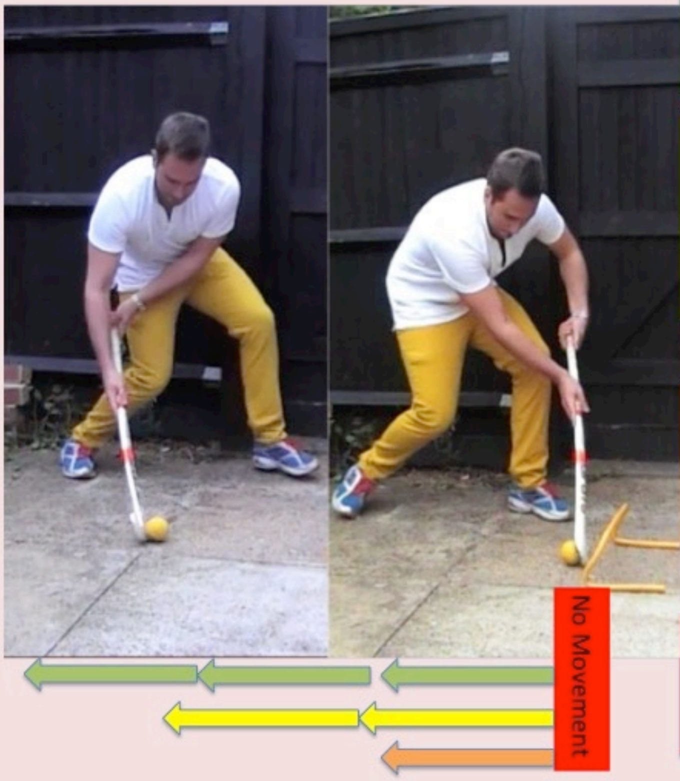
TS0. Unlikely to progress any further with the application of this technique.

Greater than + 11 degrees or no stop.

Drag back

Subcomponent B1. Backward movement body or step.

Note:
The step or sway movement enables the subject to position the stick to enable successful reverse action ball movement.



TS5. Correct technique application.

Step movement.

TS3. Progress towards the correct technique application but not fully achieved.

Exaggerated sway.

TS2. A solution based rather than technically correct attempt.

Sway but not exaggerated.

TS0. Unlikely to progress any further with the application of this technique.

No movement.

Drag back

Subcomponent B2. Speed

Note:
The reverse ball speed is a control factor that initiates lift. The greater the speed the less control.

TS5. Correct technique application.

Optimal drag back speed range 1.34-1.82m/sec.

TS3. Progress towards the correct technique application but not fully achieved.

Drag back speed < 1.34 m/sec.

TS2. A solution based rather than technically correct attempt.

Drag back speed > 1.82 m/sec.

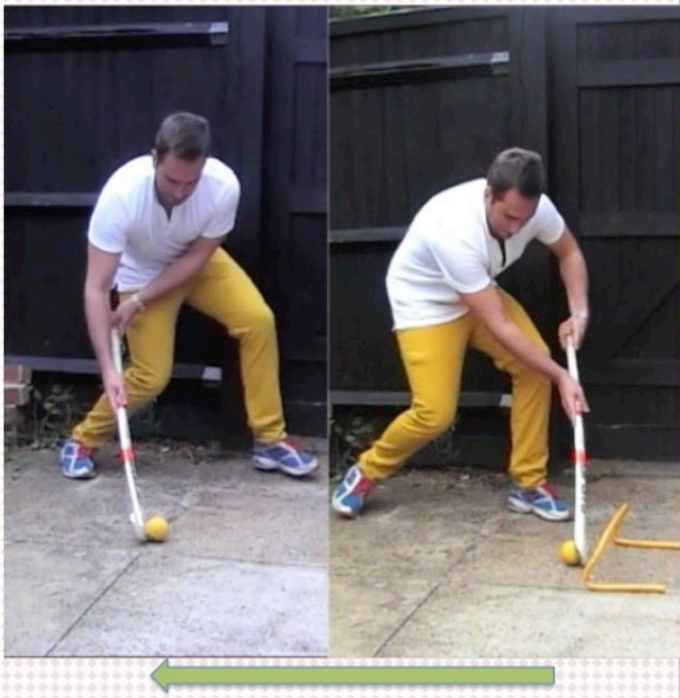
TS0. Unlikely to progress any further with the application of this technique.

Unsuccessful drag back.

Drag back

Subcomponent B3. Distance dragged.

Note:
The distance dragged is related to the stick angle in the lift stage. It is also associated with the step/sway drag back movement.



TS5. Correct technique application.

≥ .50 ≤ .70 m

TS3. Progress towards the correct technique application but not fully achieved.

> .70 m

TS2. A solution based rather than technically correct attempt.

< .50 m

TS0. Unlikely to progress any further with the application of this technique.

No movement.

Throw

Subcomponent T1. Retain hand position.

Note:
Has the hand position changed from that noted in P1.

TS5. Correct technique application.

No change.

TS3. Progress towards the correct technique application but not fully achieved.

Wider grip.

TS2. A solution based rather than technically correct attempt.

Narrower grip.

TS0. Unlikely to progress any further with the application of this technique.

Single handed grip

Throw

Subcomponent T2. Stick correct (flat edge).

Note:
Very difficult to lift the ball with the stick on reverse.

TS5. Correct technique application.

Flat side of stick.

TS3. Progress towards the correct technique application but not fully achieved.

N/A

TS2. A solution based rather than technically correct attempt.

N/A

TS0. Unlikely to progress any further with the application of this technique.

Reverse side of stick.

Throw

Subcomponent T3. Sideways on.

Note:
Is subcomponent P3 positioning maintained?

TS5. Correct technique application.

Parallel positioning allowing for ball directional movement.

TS3. Progress towards the correct technique application but not fully achieved.

N/A

TS2. A solution based rather than technically correct attempt.

Behind the ball.

TS0. Unlikely to progress any further with the application of this technique.

N/A

Throw

Subcomponent T4. Ball between stance.

Note:
Optimal positioning highlighted by the colour chart.

TS5. Correct technique application.

Score as colour coded positions.

TS3. Progress towards the correct technique application but not fully achieved.

Score as colour coded positions.

TS2. A solution based rather than technically correct attempt.

Score as colour coded positions.

TS0. Unlikely to progress any further with the application of this technique.

Score as colour coded positions.

Throw

Subcomponent T5. Stick face parallel.

Note:
Reference to P5.
At the point of ball contacts the stick face should be perpendicular to the ball to facilitate parallel ball movement.

TS5. Correct technique application.

Parallel ball movement.

TS3. Progress towards the correct technique application but not fully achieved.

Range from +10 to -10 degrees off perpendicular.

TS2. A solution based rather than technically correct attempt.

N/A

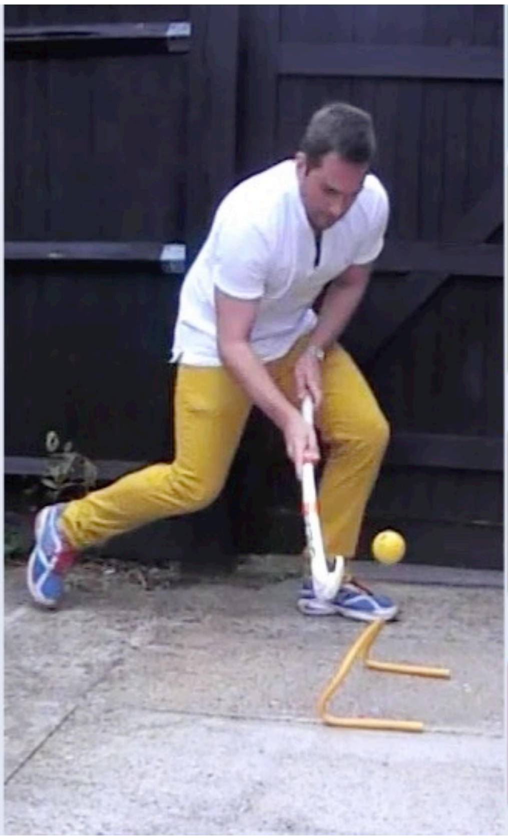
TS0. Unlikely to progress any further with the application of this technique.

Range beyond +10 to -10 degrees off parallel.

Throw

Subcomponent T6. Elevated ball.

Note:
The task objective is to lift the ball over the hurdle.



TS5. Correct technique application.

Elevated ball over hurdle.

TS3. Progress towards the correct technique application but not fully achieved.

Lifted but not above hurdle.

TS2. A solution based rather than technically correct attempt.

N/A

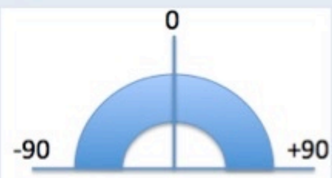
TS0. Unlikely to progress any further with the application of this technique.

Not lifted

Throw

Subcomponent T7. Drop the knee, change in stick angle or both.

Note:
The low position by bending the knee associated with the stick angle is critical to ensure a ball lift. Change from P8 in a negative direction.



TS5. Correct technique application.

Dropped knee and change in stick angle.

TS3. Progress towards rather the correct technique application but not fully achieved.

N/A

TS2. A solution based rather than technically correct attempt.

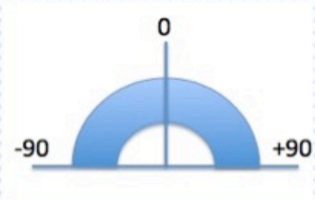
Change in stick angle.

TS0. Unlikely to progress any further with the application of this technique.

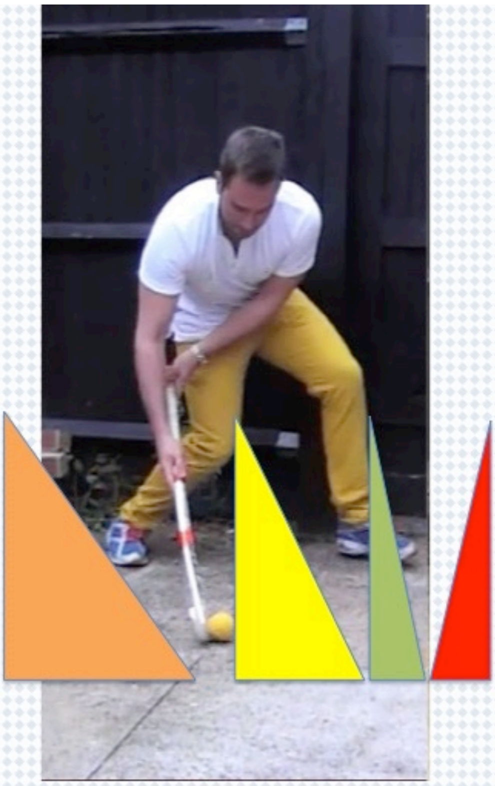
No adjustment or reverse stick attempt

Throw

Subcomponent T8. Stick angle.



Note:
Given the reverse momentum of the ball during drag back , the stick angle is associated with the ball control.



TS5. Correct technique application.

Stick angle backwards between 0 and -20 degrees.

TS3. Progress towards the correct technique application but not fully achieved.

Stick angle backwards between -21 and -35 degrees.

TS2. A solution based rather than technically correct attempt.

Stick angle backwards > -35 degrees.

TS0. Unlikely to progress any further with the application of this technique.

Stick angle forward, positive degrees.

Throw

Subcomponent T9. Throw speed.

Note:
The speed of the throw is associated with the ball control.

TS5. Correct technique application.

Throw speed range 2.39-3.23 m/sec.

TS3. Progress towards the correct technique application but not fully achieved.

Throw speed < 2.39 > .5 m/s.

TS2. A solution based rather than technically correct attempt.

Throw speed > 3.23 < 5 m/s.

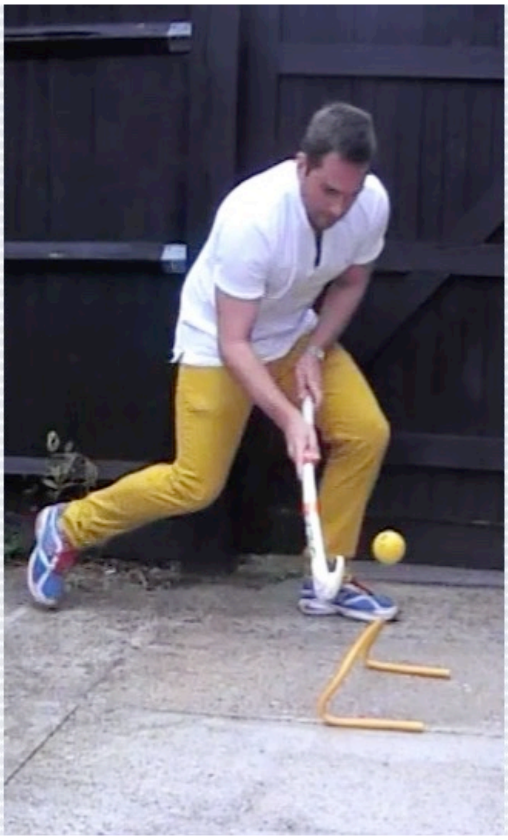
TS0. Unlikely to progress any further with the application of this technique.

Other slower or faster speeds.

Throw

Subcomponent T10.
Height above hurdle.

Note:
The relative height over the hurdle is another factor leading to ultimate control.



TS5. Correct technique application.

Throw accurate, height between 21-30 cm, above hurdle height.

TS3. Progress towards the correct technique application but not fully achieved.

Throw height below 20 cm, hurdle height.

TS2. A solution based rather than technically correct attempt.

Throw height, grossly above hurdle height.
> 31cm.

TS0. Unlikely to progress any further with the application of this technique.

No lift over hurdle.

Control

Subcomponent C1.
Forward movement.

Note:
The instigation of forward movement upon lifting the ball in anticipation of the correct execution of the throw phase.

TS5. Correct technique application.

Forward movement.

TS3. Progress towards the correct technique application but not fully achieved.

N/A

TS2. A solution based rather than technically correct attempt.

N/A

TS0. Unlikely to progress any further with the application of this technique.

No forward movement.

Control

Subcomponent C2. Stick correct edge.

Note:
Ball control is considerably enhanced by using a the flat stick edge; although it is possible to control with the reverse side.

TS5. Correct technique application.

Control with flat edge.

TS3. Progress towards the correct technique application but not fully achieved.

N/A

TS2. A solution based rather than technically correct attempt.

Reverse stick.

TS0. Unlikely to progress any further with the application of this technique.

N/A

Control

Subcomponent C3. Ball position.

Note:
The position of where the ball lands.

TS5. Correct technique application.

On spot.

TS3. Progress towards the correct technique application but not fully achieved.

Between spot and hurdle.

TS2. A solution based rather than technically correct attempt.

Beyond hurdle.

TS0. Unlikely to progress any further with the application of this technique.

All other positions

Appendix B

Declarative knowledge and perceived skill questionnaire.

Research Participant Number:
Research Participant Name:

On a scale of 1-5 identify your knowledge and perceived skill at the following sports based on the scale below.

Description	Very low	Low	Moderate	High	Very High
Knowledge	1	2	3	4	5
Perceived skill	1	2	3	4	5

The participant should answer every question	Knowledge	Perceived skill
1. Field Hockey		
2. Hurling (Irish stick and ball game)		
3. Cricket		
4. Tennis		
5. Lacrosse		
6. Football		
7. Netball		
8. Basketball		
9. Roller Hockey		
10. Ice Hockey		

Appendix C

The first session motivation questionnaire

Research Participant Number:
Research Participant Name:

On a scale of 1-5 identify your motivation levels on each test.

Description	Very low	Low	Moderate	High	Very High
Motivation	1	2	3	4	5

Task	Question	Motivation

1. Hockey Skill		
i	How motivated are you?	
	How irritated are you?	
	How interested in the task are you?	
2. Spot the word	How motivated are you?	
ii	How irritated are you?	
	How interested in the task are you?	
3. Ravens test	How motivated are you?	
iii	How irritated are you?	
iv	How interested in the task are you?	

Appendix D

The second session motivation questionnaire

Research Participant Number:
Research Participant Name:

On a scale of 1-5 identify your motivation levels on each test.

Description	Very low	Low	Moderate	High	Very High
Motivation	1	2	3	4	5

Task	Question	Motivation
4. Fitts Law		
v	How motivated are you?	
	How irritated are you?	
	How interested in the task are you?	
5. Working memory	How motivated are you?	
vi	How irritated are you?	
	How interested in the task are you?	
6. Inspection time	How motivated are you?	
vii	How irritated are you?	
viii	How interested in the task are you?	

Appendix E

Hockey results: - Mean and standard deviation measures of motivation, irritation and interest.

Mean and standard motivation, irritation, and interest (n=40) in each task scored by the 5-point Likert scale from 1 (very low), 2 (low), 3 (moderate), 4 (high) and 5 (very high).

Task	Motivation	Irritation	Interest
Hockey	3.53 (0.96)	3.03 (1.17)	3.73 (1.09)
OSpan	3.70 (0.97)	3.20 (1.38)	3.68 (1.07)
Ravens SPM	3.60 (1.06)	2.75 (1.24)	3.70 (1.04)
Spot-the-Word	3.43 (1.13)	2.08 (1.12)	3.30 (1.18)
Inspection Time	3.20 (0.99)	2.78 (1.21)	2.93 (1.23)
Fitts' Law	3.95 (0.88)	1.78 (1.19)	3.78 (1.12)

References

Abd El Shakour. (2020). Psychomotor Abilities as a prediction indicator of high-level performance in tennis. *The International Scientific Journal of Physical Education and Sport Sciences,*

Ackerman, P. L. (1984). *A theoretical and empirical investigation of individual differences in learning: A synthesis of cognitive ability and information processing perspective.*

Ackerman, P. L. (1987). Individual Differences in Skill Learning: An Integration of Psychometric and Information Processing Perspectives. *Psychological Bulletin, 102*(1), 3-27. 10.1037/0033-2909.102.1.3

Ackerman, P. L. (1988). Determinants of Individual Differences During Skill Acquisition: Cognitive Abilities and Information Processing. *Journal of Experimental Psychology; General, 117*(1), 288.

Ackerman, P. L. (1990). A Correlational Analysis of Skill Specificity: Learning, Abilities, and Individual Differences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*(5), 883-901. 10.1037/0278-7393.16.5.883

Ackerman, P. L. (2007). Outgoing Editorial: Bridging Science and Application. *Journal of Experimental Psychology: Applied, 13*(4), 179-181. 10.1037/1076-898X.13.4.179

Ackerman, P. L. (2014). Nonsense, common sense, and science of expert performance: Talent and individual differences. *Intelligence, 45*, 6-17. 10.1016/j.intell.2013.04.009

Ackerman, P. L., & Cianciolo, A. T. (2000). Cognitive, Perceptual-Speed, and Psychomotor Determinants of Individual Differences During Skill Acquisition. *Journal of Experimental Psychology: Applied, 6*(4), 259-290. 10.1037/1076-898X.6.4.259

Ackerman, P. L., & Heggestad, E. D. (1997). Intelligence, personality, and interests: evidence for overlapping traits. *Psychological Bulletin, 121*(2), 219-245. 10.1037/0033-2909.121.2.219

Ackerman, P. L., Kanfer, R., & Goff, M. (1995). Cognitive and Noncognitive Determinants and Consequences of Complex Skill Acquisition. *Journal of Experimental Psychology: Applied, 1*(4), 270-304. 10.1037/1076-898X.1.4.270

Ahmetov, I. I., & Fedotovskaya, O. N. (2012). Sports genomics: Current state of knowledge and future directions. *Cellular and Molecular Exercise Physiology, 1*(1), 1-24. 10.7457/cmep.v1i1.e1

Allen, M. S., Greenlees, I., & Jones, M. (2013). Personality in sport: A comprehensive review. *International Review of Sport and Exercise Psychology, 6*(1), 184-208.

Aloraini, S. M., Gelley, G., Glazebrook, C., Sibley, K. M., Singer, J., & Passmore, S. (2020). Motor behavior concepts in the study of balance: a scoping review. *Journal of Motor Behavior, 52*(1), 97-121.

Anderson, J. R. (1987). Skill Acquisition: Compilation of Weak-Method Problem Solutions. *Psychological Review, 94*(2), 192-210. 10.1037/0033-295X.94.2.192

Anderson, J. R. (1993). *Rules of the Mind*. Lawrence Erlbaum.

Anderson, J. R. (1996). ACT: A Simple Theory of Complex Cognition. *American Psychologist, 51*(4), 355-365. 10.1037/0003-066X.51.4.355

Anderson, J. R. (2007). *How can the human mind occur in the physical universe?*. Oxford University Press.

Anguera, J. A., Reuter-Lorenz, P. A., Willingham, D. T., & Seidler, R. D. (2010). Contributions of spatial working memory to visuomotor learning. *Journal of Cognitive Neuroscience, 22*(9), 1917-1930. 10.1162/jocn.2009.21351

Armstrong, N., Williams, J., Balding, J., Gentle, P., & Kirby, B. (1991). The peak oxygen uptake of British children with reference to age, sex and sexual maturity. *European Journal of Applied Physiology and Occupational Physiology, 62*(5), 369-375. 10.1007/BF00634975

B.B.C. (n.d.). *Team GB: Which athletes have booked their London 2012?* Retrieved January 18th 2013, from http://www.bbc.co.uk/sport/0/olympics/16384137

Baddeley, A. (1992). Working Memory. *Science, 255*(5044), 556-559. 10.1126/science.1736359

Baddeley, A. (2010). Working memory. *Current Biology, 20*(4), R136-R140. 10.1016/j.cub.2009.12.014

Baddeley, A., Emslie, H., & Nimmosmith, I. (1993). The Spot-the-Word test: A robust estimate of
verbal intelligence based on lexical decision. *British Journal of Clinical Psychology, 32*(1), 55-65.

Bagley, W. C. (1901). On the correlation of mental and motor ability in scholl children. *American Journal of Psychology, 12*, 193-205.

Baker, J. (2003). Early specialization in youth sport: a requirement for adult expertise? *High Ability Studies, 14*(1), 85-94. 10.1080/13032000093526

Baker, J., Côté, J., & Abernethy, B. (2003). Sport-specific practice and the development of expert decision-making in team ball sports. *Journal of Applied Sport Psychology, 15*(1), 12-25. 10.1080/10413200390180035

Baker, J., Côté, J., & Deakin, J. (2005). Expertise in ultra-endurance triathletes early sport involvement, training structure, and the theory of deliberate practice. *Journal of Applied Sport Psychology, 17*(1), 64-78. 10.1080/10413200590907577

Baker, J., Deakin, J., & Côté, J. (2005). On the utility of deliberate practice: Predicting performance in ultra-endurance triathletes from training indices. *International Journal of Sport Psychology, 36*(3), 225-240.

Baker, J., Horton, S., Robertson-Wilson, J., & Wall, M. (2003). Nurturing sport expertise: factors influencing the development of elite athlete. *Journal of Sports Science & Medicine, 2*(1), 1-9.

Baker, J., Cobley, S., & Fraser-Thomas, J. (2009). What do we know about early sport specialization? Not much! *High Ability Studies, 20*(1), 77-89.

Bandura, A., & Walters, R. H. (1977). *Social learning theory*. Englewood cliffs Prentice Hall.

Barnett, A., Henderson, S. E. & Sugden, D. A. (2007). *Movement Assessment Battery for Children 2nd Edition (MABC-2)*. http://www.pearsonclinical.co.uk/Psychology/ChildCognitionNeuropsychologyandLanguage/ChildPerceptionandVisuomotorAbilities/MABC-2/MovementAssessmentBatteryforChildren-SecondEdition(MovementABC-2).aspx

Barreiros, A., Côté, J., & Fonseca, A. M. (2013). Training and psychosocial patterns during the early development of Portuguese national team athletes. *High Ability Studies, 24*(1), 49-61. 10.1080/13598139.2013.780965

Barth, M., Emrich, E., & Güllich, A. (2019). A Machine Learning Approach to “Revisit” Specialization and Sampling in Institutionalized Practice. *SAGE Open, 9*(2), 2158244019840554.

Barynina, I.I., & Vaitsekhovskii, S.M. (1992). The aftermath of early sports specialization for highly qualified swimmers. *Fitness and Sports Review International, 27*(4), 132-133.

Bathish, M., Wilson, C., & Potempa, K. (2018). Deliberate practice and nurse competence. *Applied Nursing Research, 40*, 106-109.

Baxter-Jones, A. D. (1995). Growth and development of young athletes. Should competition levels be age related? *Sports Medicine, 20*(2), 59.

Beaman, C. P. (2004). The irrelevant sound phenomenon revisited: What role for working memory capacity? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(5), 1106.

Becker, M., Lüdtke, O., Trautwein, U., Köller, O., & Baumert, J. (2012). The differential effects of school tracking on psychometric intelligence: Do academic-track schools make students smarter? *The Journal of Educational Psychology, 104*(3), 682; 699-699. 10.1037/a0027608

Beech, J. R., & Harding, L. (1990). *Testing people: a practical guide to psychometrics*. NFER-Nelson.

Beier, M. E., & Ackerman, P. L. (2004). A reappraisal of the relationship between span memory and intelligence via "best evidence synthesis". *Intelligence, 32*(6), 607-619. 10.1016/j.intell.2004.07.005

Berry, D. C., & Broadbent, D. E. (1988). Interactive Tasks and the Implicit-Explicit Distinction. *British Journal of Psychology, 79*(2), 251-272. 10.1111/j.2044-8295.1988.tb02286.x

Beunen, G., & Thomis, M. (1999). Genetic determinants of sports participation and daily physical activity. *International Journal of Obesity, 23*(3), S55-S63.

Bloom, B. S. (1985). Developing talent in young people. In B. S. Bloom (Ed.), *Generalizations about talent development.* (pp. 507-549). Ballantine Books.

Bo, J., Borza, V., & Seidler, R. D. (2009). Age-Related Declines in Visuospatial Working Memory Correlate With Deficits in Explicit Motor Sequence Learning. *Journal of Neurophysiology, 102*(5), 2744-2754. 10.1152/jn.00393.2009

Bolton, T. L. (1903). The relation of motor power to intelligence. *American Journal of Psychology, 14*, 351-357.

Bompa, T. O., & Carrera, M. (2005). *Periodization training for sports* (2nd ed.). Human Kinetics.

Bouchard, C., Malina, R. M., & Perusse, L. (1997). *Genetics of Fitness and Physical Performance*. Human Kinetics.

British Cycling. (2021). *British Cycling Handbook 2021* (2021st ed.). Newhall.

British Cycling. (n.d.). *Rider Biographies.* Retrieved 07/09 2013, from http://www.britishcycling.org.uk/gbcyclingteam/article/Gbrst_Great-Britain-Cycling-Team-Olympic-Programmes

Buszard, T., Masters, R. S., & Farrow, D. (2017). The generalizability of working-memory capacity in the sport domain. *Current Opinion in Psychology, 16*, 54-57.

Carlson, R. C. (1997). In search of the expert performer. *Science in the Olympic Sport, 1*, 1-13.

Carter, L., River, B., & Sachs, M. L. (2013). Flow in Sport, Exercise, and Performance: A Review with Implications for Future Research. *Journal of Multidisciplinary Research (1947-2900), 5*(3)

Casler, K., Bickel, L., & Hackett, E. (2013). Separate but equal? A comparison of participants and data gathered via Amazon's MTurk, social media, and face-to-face behavioral testing. *Computers in Human Behavior, 29*(6), 2156. 10.1016/j.chb.2013.05.009

Chan, S., Seto, J. T., MacArthur, D. G., Yang, N., North, K. N., & Head, S. I. (2008). A gene for speed: contractile properties of isolated whole EDL muscle from an alpha-actinin-3 knockout mouse. *American Journal of Physiology.Cell Physiology, 295*(4), C897-C904. 10.1152/ajpcell.00179.2008

Chassy, P., & Gobet, F. (2010). Speed of Expertise Acquisition Depends upon Inherited Factors. *Talent Development and Excellence, 2*(1), 17-27.

Coffee, P., & Rees, T. (2011). When the chips are down: Effects of attributional feedback on self-efficacy and task performance following initial and repeated failure. *Journal of Sports Sciences, 29*(3), 235-245.

Coffee, P., Rees, T., & Haslam, S. A. (2009). Bouncing back from failure: The interactive impact of perceived controllability and stability on self-efficacy beliefs and future task performance. *Journal of Sports Sciences, 27*(11), 1117-1124.

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Academic press.

Coleman, A. M. (2015). *A dictionary of Phsycology* (4th ed.). Oxford University Press. 10.1093/acref/9780199657681.001.0001

Collins, D., & MacNamara, A. (2011). Comments on 'expert performance in sport and the dynamics of talent development'. *Sports Medicine, 41*(7), 609-610. 10.2165/11593020-000000000-00000

Crisp, P. (2019). Sidestepping Talent ID Models: Avoiding Early Specialisation, Maintaining Participation, and Focusing on the Participant as an Athlete. *Journal of Sport and Games, 1*(4), 16-21.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450-466.

Daneman, M., & Carpenter, P. A. (1983). Individual differences in integrating information between and within sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*(4), 561.

Daniels, J., & Scardina, N. (1984). Interval training and performance. *Sports Medicine, 1*(4), 327-334.

Davids, K., & Baker, J. (2007). *Genes, Environment and Sport Performance: Why the Nature-Nurture Dualism is no Longer Relevant*. Adis International. 10.2165/00007256-200737110-00004

Davis, E. E., Pitchford, N. J., Jaspan, T., McArthur, D., & Walker, D. (2010). Development of cognitive and motor function following cerebellar tumour injury sustained in early childhood. *Cortex, 46*(7), 919-932. 10.1016/j.cortex.2009.10.001

Davis, E. E., Pitchford, N. J., & Limback, E. (2011). The interrelation between cognitive and motor development in typically developing children aged 4-11 years is underpinned by visual processing and fine manual control. *British Journal of Psychology (London, England : 1953), 102*(3), 569.

Deary, I. J., & Mitchell, H. (1989). Inspection time and high-speed ball games. *Perception, 18*(6), 789-792.

Devlin, B., Daniels, M., & Roeder, K. (1997). The heritability of IQ. *Nature, 388*(6641), 468-471.

DiFiori, J. P., Brenner, J. S., Comstock, D., Côté, J., Güllich, A., Hainline, B., & Malina, R. (2017). Debunking early single sport specialisation and reshaping the youth sport experience: an NBA perspective. *British Journal of Sports Medicine,*

Dreyfus, H. L., Dreyfus, S. E., & Athanasiou, T. (1988). *Mind over machine: the power of human intuition and expertise in the era of the computer*. Free Press.

Ehmann, P., Beavan, A., Spielmann, J., Mayer, J., Ruf, L., Altmann, S., Forcher, L., Klever, N., Rohrmann, S., & Nuß, C. (2022). Perceptual-cognitive performance of youth soccer players in a 360°-environment–An investigation of the relationship with soccer-specific performance and the effects of systematic training. *Psychology of Sport and Exercise,* , 102220.

Ehmann, P., Beavan, A., Spielmann, J., Ruf, L., Mayer, J., Rohrmann, S., Nuß, C., & Englert, C. (2021). 360°-multiple object tracking in team sport athletes: Reliability and relationship to visuospatial cognitive functions. *Psychology of Sport and Exercise, 55*, 101952.

Eltoukhy, M., Asfour, S., Thompson, C., & Latta, L. (2012). Evaluation of the Performance of Digital Video Analysis of Human Motion: Dartfish Tracking System. *International Journal of Scientific & Engineering Research, 3*(3)SSN 2229-5518

English Sports Council. (1998). *The development of sporting talent 1997: an examination of the current practices for talent development in English sport.* ().English Sports Council.

Ericsson, K. A. (2016). Summing Up Hours of Any Type of Practice Versus Identifying Optimal Practice Activities: Commentary on Macnamara, Moreau, & Hambrick (2016). *Perspectives on Psychological Science, 11*(3), 351-354. 10.1177/1745691616635600

Ericsson, K. A. (2020). Towards a science of the acquisition of expert performance in sports: Clarifying the differences between deliberate practice and other types of practice. *Journal of Sports Sciences, 38*(2), 159-176.

Ericsson, K. A., Krampe, R. T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*, 363-406.

Ericsson, K. A., Prietula, M. J., & Cokely, E. T. (2007). *The making of an expert.* Harvard Business School Press.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: verbal reports as data* (Rev. ed.). MIT Press.

Eysenck, H. J., Nias, D., & Cox, D. N. (1982). Sport and personality. *Advances in Behaviour Research and Therapy, 4*(1), 1-56.

Faber, I. R., Bustin, P. M., Oosterveld, F. G., Elferink-Gemser, M. T., & Nijhuis-Van der Sanden, M. W. (2016). Assessing personal talent determinants in young racquet sport players: a systematic review. *Journal of Sports Sciences, 34*(5), 395-410.

Falk Neto, J. H., & Kennedy, M. D. (2019). The multimodal nature of high-intensity functional training: potential applications to improve sport performance. *Sports, 7*(2), 33.

Field, A. P. (2009). *Discovering statistics using SPSS: and sex and drugs and rock 'n' roll*. SAGE.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47*(6), 381-391. 10.1037/h0055392

Fitts, P. M. (1964). Perceptual-motor skill learning. In A. W. Melton (Ed.), *Categories of human learning* (pp. 243-285). Academic Press.

Fitts, P. M., & Posner, M. I. (1967). *Human performance*. Brooks/Cole.

Fleishman, E. A., & Quaintance, M. K. (1984). *Taxonomies of Human Performance*. Academic Press.

Foley, J. P., Bird, S. R., & White, J. A. (1989). Anthropometric comparison of cyclists from different events. *British Journal of Sports Medicine, 23*(1), 30-33. 10.1136/bjsm.23.1.30

Ford, P. R., & Williams, A. M. (2008). The Effect of Participation in Gaelic Football on the Development of Irish Professional Soccer Players. *Journal of Sport & Exercise Psychology, 30*(6), 709-722.

Ford, P. R., & Williams, A. M. (2012). The developmental activities engaged in by elite youth soccer players who progressed to professional status compared to those who did not. *Psychology of Sport and Exercise, 13*, 349-352. 10.1016/j.psychsport.2011.09.004

Ford, P. R., Coughlan, E. K., Hodges, N. J., & Williams, A. M. (2015). Deliberate practice theory and supporting data.

Fox, E. L., Bowers, R. W., & Foss, M. L. (1993). *The physiological basis for exercise and sport*. Brown & Benchmark.

Fu, J. (2000). **A Study on Relationship between Intelligence and Athletic Skills of Guards in Chinese Women's Basketball Team**. *Sport Science and Technology, 21*(3), 27-30.

Furley, P. A., & Memmert, D. (2010). The role of working memory in sport. *International Review of Sport and Exercise Psychology, 3*(2), 171-194.

Gardner, H. (1983). *Frames of mind: the theory of multiple intelligences*. BasicBooks.

GB Rowing Team. (2009). *Tall and Talented wanted to try out for the 2016 Olympic Games.* https://www.britishrowing.org/2009/10/tall-and-talented-wanted-to-try-out-for-the-2016-olympic-games/.

Ge, C. L. (1997). Research on Intelligence Characteristics of Chinese Excellent Junior Volleyball Athletes. . *Sports Sciences Researches, 1*, 15-21.

Gendron, D., & Stenlund, K. V. (2003). *Coaching hockey successfully*. Human Kinetics 1.

Gibala, M. J., MacDougall, J. D., Tarnopolsky, M. A., Stauber, W. T., & Elorriaga, A. (1995). Changes in human skeletal muscle ultrastructure and force production after acute resistance exercise. *Journal of Applied Physiology, 78*(2), 702-708.

Gill, G. S. (2016). Examining the impact of emotional intelligence and goal setting on basketball performance. *Sport Journal, 1*(8)

Gladwell, M. (2009). *Outliers: the story of success*. Penguin Books.

Gobet, F., & Ereku, M. H. (2014). Checkmate to deliberate practice: the case of Magnus Carlsen. *Frontiers in Psychology, 5*, 878. 10.3389/fpsyg.2014.00878

Gobet, F. (2013). Expertise vs. Talent. *Talent Development & Excellence, 5*(1), 75-86.

Gobet, F. (2015). *Understanding expertise:A multidisciplinary approach.* . Palgrave.

Gobet, F., & Campitelli, G. (2007). The Role of Domain-Specific Practice, Handedness, and Starting Age in Chess. *Developmental Psychology, 43*(1), 159-172. 10.1037/0012-1649.43.1.159

Gosling, S. D., Gaddis, S., & Vazire, S. (2007). Personality impressions based on facebook profiles. Paper presented at the *International Conference on Weblogs and Social Media,* Boulder, Colorado, USA.

Gould, D., & Petlickhoff, L. (1988). Participation, motivation and attrition in young athletes. In F. L. Smoll, R. A. Magill & M. Ash (Eds.), *Children in Sport.* (3rd ed., pp. 161-178). Human Kinetics.

Grandou, C., Wallace, L., Impellizzeri, F. M., Allen, N. G., & Coutts, A. J. (2020). Overtraining in resistance exercise: an exploratory systematic review and methodological appraisal of the literature. *Sports Medicine, 50*(4), 815-828.

Gregory, T., Nettelbeck, T., & Wilson, C. (2010). Openness to experience, intelligence, and successful ageing. *Personality and Individual Differences, 48*(8), 895-899.

Griffin, G. :. (n.d.). *Core Skills for Hockey.* http://www.whitfordhockey.asn.au/cms/wp-content/uploads/2012/02/hockey-core-skills.pdf

Güllich, A. (2014). Many roads lead to Rome - Developmental paths to Olympic gold in men's field hockey. *European Journal of Sport Science, 14*(8), 763-771. 10.1080/17461391.2014.905983

Güllich, A. (2017). International medallists' and non-medallists' developmental sport activities - a matched-pairs analysis. *Journal of Sports Sciences, 35*(23), 2281-2288. 10.1080/02640414.2016.1265662

Güllich, A. (2018a). “Macro-structure” of developmental participation histories and “micro-structure” of practice of German female world-class and national-class football players. *Journal of Sports Sciences,* , 1-9. 10.1080/02640414.2018.1558744

Güllich, A. (2018b). Sport-specific and non-specific practice of strong and weak responders in junior and senior elite athletics - A matched-pairs analysis. *Journal of Sports Sciences, 36*(19), 2256-2264. 10.1080/02640414.2018.1449089

Güllich, A., & Emrich, E. (2012). Individualistic and collectivistic approach in athlete support programmes in the German high-performance sport system. *European Journal for Sport and Society, 9*(4), 243-268.

Güllich, A., & Emrich, E. (2014). Considering long-term sustainability in the development of world class success. *European Journal of Sport Science, 14 Suppl 1*(sup1), S383-S397. 10.1080/17461391.2012.706320

Güllich, A., Faß, L., Gies, C., & Wald, V. (2020). On the Empirical Substantiation of the Definition of "Deliberate Practice" (Ericsson et al., 1993) and "Deliberate Play" (Côté et al., 2007) in Youth Athletes. *Journal of Expertise/March, 3*(1)

Hagan Jr, J. E., Pollmann, D., & Schack, T. (2017). Elite athletes' in-event competitive anxiety responses and psychological skills usage under differing conditions. *Frontiers in Psychology, 8*, 2280.

Hambrick, D. Z., Burgoyne, A. P., Macnamara, B. N., & Ullén, F. (2018). Toward a multifactorial model of expertise: beyond born versus made. *Annals of the New York Academy of Sciences, 1423*(1), 284-295. 10.1111/nyas.13586

Han, X., & Paine, L. (2010). Teaching Mathematics as Deliberate Practice through Public Lessons. *Elementary School Journal, 110*(4), 519-541.

Hay, P. J., & Macdonald, D. (2010). Evidence for the social construction of ability in physical education. *Sport, Education and Society, 15*(1), 1-18.

Helsen, W. F., Hodges, N. J., Van Winckel, J., & Starkes, J. L. (2000). The roles of talent, physical precocity and practice in the development of soccer expertise. *Journal of Sports Sciences, 18*(9), 727-736. 10.1080/02640410050120104

Helsen, W. F., Starkes, J. L., & Hodges, N. J. (1998). Team sports and the theory of deliberate practice. *Journal of Sport and Exercise Psychology., 20*(1), 12-34.

Hill, K. (2014). Using mobile devices for motor-learning laboratory exercises. *Journal of Physical Education, Recreation and Dance, 85*(8), 20-26.

Hoaglin, D. C., & Iglewicz, B. (1987). Fine-Tuning Some Resistant Rules for Outlier Labeling. *Journal of the American Statistical Association, 82*(400), 1147-1149.

Hoaglin, D. C., Iglewicz, B., & Tukey, J. W. (1986). Performance of Some Resistant Rules for Outlier Labeling. *Journal of the American Statistical Association, 81*(396), 991-999.

Hoare, D. G., & Warr, C. R. (2000). Talent identification and women's soccer: An Australian experience. *Journal of Sports Sciences, 18*(9), 751-758. 10.1080/02640410050120122

Hodges, N. J., & Starkes, J. L. (1996). Wrestling with the nature of expertise: A sport specific test of Ericsson, Krampe and Tesch-Romer's (1993) theory of ''deliberate practice'. *International Journal of Sport Psychology, 27*(4), 400-424.

Hodges, N. J., Kerr, T., Starkes, J. L., & Weir, P. L. &. N., A. (2004). Predicting performance times from deliberate practice hours for triathletes and swimmers: What, when and where is practice important. *Journal of Experimental Psychology: Applied., 10*(4), 219-237. 10.1037/1076-898X.10.4.219

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26*(2), 107-129. 10.1016/0001-6918(67)90011-X

Horn, J. L. (1965). *Fluid and crystallized intelligence: A factor analytic study of the structure among primary mental abilities.* Ann Arbor.

Howe, M. J. H., Davidson, J. W., & Sloboda, J. A. (1998). Innate talents: Reality or Myth? . *Behavioral and Brain Sciences, 21*, 399-407.

Humphreys, L. G. (1979). The construct of general intelligence. *Intelligence, 3*(2), 105-120. 10.1016/0160-2896(79)90009-6

Hunter, D. R., & Burke, E. F. (1994). Predicting aircraft pilot-training success: A meta-analysis of published research. *The International Journal of Aviation Psychology, 4*, 297-313.

Hyllegard, R., Radlo, S. J., McElroy, L., & Krejca, W. (2002). Is deliberate practice inherently enjoyable? Deliberate practice theory and sport. *Journal of Sport & Exercise Psychology, 24*, 73.

Hyllegard, R., & Yamamoto, M. (2007). Testing assumptions of deliberate practice theory relevance, effort, and inherent enjoyment of practice with a novel task: study II. *Perceptual and Motor Skills, 105*(2), 435-446. 10.2466/PMS.105.2.435-446

Impellizzeri, F. M., Rampinini, E., Sassi, A., Mognoni, P., & Marcora, S. (2005). Physiological correlates to off-road cycling performance. *Journal of Sports Sciences, 23*(1), 41-47.

International Olympic Committee. (2012). *Factsheet. The programme of the games of the Olympiad. Update-July 2012.* (). www.olympic.org/Documents/Referemce_documents_Factsheets/Olympic_Summer_Programme.pdf

Johann, V., Könen, T., & Karbach, J. (2020). The unique contribution of working memory, inhibition, cognitive flexibility, and intelligence to reading comprehension and reading speed. *Child Neuropsychology, 26*(3), 324-344.

Junwu, D. (2012). The research on sports intelligence in China. Paper presented at the *Advanced Technology in Teaching-Proceedings of the 2009 3rd International Conference on Teaching and Computational Science (WTCS 2009),* 743-752.

Kanfer, R., & Ackerman, P. L. (1989). Motivation and cognitive-abilities - An integrative aptitude treatment interaction approach to skill acquisition. *Journal of Applied Psychology, 74*(4), 657-690. 10.1037/0021-9010.74.4.657

Kenney, W. L., Wilmore, J. H., & Costill, D. L. (2012). *Physiology of sport and exercise*. Human Kinetics.

King, D. B., O'Rourke, N., & DeLongis, A. (2014). Social Media Recruitment and Online Data Collection: A Beginner's Guide and Best Practices for Accessing Low-Prevalence and Hard-to-Reach Populations. *Canadian Psychology, 55*(4), 240.

Kordi, A. M., Folland, J., Goodall, S., Menzies, C., Patel, T. S., Evans, M., Thomas, K., & Howatson, G. (2020). Cycling-specific isometric resistance training improves peak power output in elite sprint cyclists. *Scandinavian Journal of Medicine & Science in Sports,*

Krawczyk, P., Bodasiński, S., Bodasińska, A., & Słupczyński, B. (2019). The Level of Psychomotor Abilities as a Factor Differentiating Handball Goalkeepers' Actions in Saves from the Wing Position. *Polish Journal of Sport and Tourism, 26*(4), 3-10.

Krombholz, H. (1997). Physical performance in relation to age, sex, social class and sports activities in kindergarten and elementary school. *Perceptual and Motor Skills, 84*(3 Pt 2), 1168-1170. 10.2466/pms.1997.84.3c.1168

Kruger, J., & Dunning, D. (1999). Unskilled and Unaware of It: How Difficulties in Recognizing One's Own Incompetence Lead to Inflated Self-Assessments. *Journal of Personality and Social Psychology, 77*(6), 1121-1134. 10.1037/0022-3514.77.6.1121

Lambourne, K., & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis. *Brain Research, 1341*, 12-24.

Laubacher, J. (2020). No title. *Comparing the Effects of Exercise on Working Memory in Collegiate Athletes Vs Non-Collegiate Athletes,* Law, M., Côté, J., & Ericsson, K. A. (2007). Characteristics of expert development in rhythmic gymnastics: A retrospective study. *International Journal of Sport Psychology, 5*, 82-103.

Leahey, T. M., Gorin, A. A., Wyckoff, E., Denmat, Z., O'Connor, K., Field, C., Dunton, G. F., Gunstad, J., Huedo-Medina, T. B., & Gilder, C. (2020). Episodic future thinking, delay discounting, and exercise during weight loss maintenance: The PACE trial. *Health Psychology, 39*(9), 796.

Lehner, B. (2013). Genotype to phenotype: lessons from model organisms for human genetics. *Nature Reviews Genetics, 14*(3), 168-178.

Lenth, R. V. (2001). Some practical guidelines for effective sample size determination. *The American Statistician, 55*(3), 187-193.

Lettre, G. (2009). Genetic regulation of adult stature. *Current Opinion in Pediatrics, 21*(4), 515-522. 10.1097/MOP.0b013e32832c6dce

Li, K., & Xiong, Z. (1993). Intelligence test and analyse to students in speciality of physical culture—A Study of Difference in intelligence Between Motor Learning And Learning of Knowledge. *Journal of Hubei University (Natural Sciences), 15*(3), 336-340.

Lidor, R., Côté, J., & Hackfort, D. (2009). ISSP position stand: To test or not to test? The use of physical skill tests in talent detection and in early phases of sport development. *International Journal of Sport and Exercise Psychology, 7*(2), 131-146. 10.1080/1612197X.2009.9671896

Lievens, F., & Patterson, F. (2011). The validity and incremental validity of knowledge tests, low-fidelity simulations, and high-fidelity simulations for predicting job performance in advanced-level high-stakes selection. *The Journal of Applied Psychology, 96*(5), 927-940. 10.1037/a0023496

Littlewood, H. (1964). Training for Sport. *Bulletin-British Association of Sport and Medicine, 1*(1), 5.

Lombardo, M. P., & Deaner, R. O. (2014). You can't teach speed: sprinters falsify the deliberate practice model of expertise. *PeerJ, 2*, e445.

Lopes, M., & Vallerand, R. J. (2020). The role of passion, need satisfaction, and conflict in athletes' perceptions of burnout. *Psychology of Sport and Exercise,* , 101674.

Lorås, H., Haga, M., & Sigmundsson, H. (2020). Effect of a Single Bout of Acute Aerobic Exercise at Moderate-to-Vigorous Intensities on Motor Learning, Retention and Transfer. *Sports, 8*(2), 15.

Lydiard, A., & Gilmour, G. (2000). *Running with Lydiard*. Meyer & Meyer Verlag.

MacNamara, A., Button, A., & Collins, D. (2010). The Role of Psychological Characteristics in Facilitating the Pathway to Elite Performance Part 1: Identifying Mental Skills and Behaviors. *Sport Psychologist, 24*(1), 52-73.

Macnamara, B. N., Hambrick, D. Z., & Oswald, F. L. (2014). Deliberate Practice and Performance in Music, Games, Sports, Education, and Professions: A Meta-Analysis. *Psychological Science, 25*(8), 1608-1618. 10.1177/0956797614535810

Magill, R. A. (2001). *Motor learning: concepts and applications*. McGraw-Hill.

Malina, R. M. (1994). Physical growth and biological maturation of young athletes. *Exercise and Sport Sciences Reviews, 22*, 389.

Malina, R. M. (2010). Early sport specialization: roots, effectiveness, risks. *Current Sports Medicine Reports, 9*(6), 364-371.

Malina, R. M., Eisenmann, J. C., Cumming, S. P., Ribeiro, B., & Aroso, J. (2004). Maturity-associated variation in the growth and functional capacities of youth football (soccer) players 13–15 years. *European Journal of Applied Physiology, 91*(5), 555-562. 10.1007/s00421-003-0995-z

Martinussen, M. (1996). Psychological predictors of pilot performance. *The International Journal of Aviation Psychology, 6*, 1-20.

McClelland, D. C., Atkinson, J. W., Clark, R. W., & Lowell, E. L. (1953). *The acheivement motive*. Appleton Century Crofts.

Memmert, D., Baker, J., & Bertsch, C. (2010). Play and practice in the development of sport-specific creativity in team ball sports. *High Ability Studies, 21*(1), 3-18. 10.1080/13598139.2010.488083

Miller, A., Galanter, E., & Pribram, K. H. (1962). *Plans and the Structure of Behavior*. American Journal of Psychology. 10.2307/1419559

Miller, G. A. (1956). The magical number seven plus or minus two: some limits on our capacity for processing information. *Psychological Review, 63*(2), 81-97. 10.1037/h0043158

Mitchell-Taverner, C. (2005). *Field hockey techniques & tactics*. Human Kinetics.

Moesch, K., Elbe, A. -, Hauge, M. - T., & Wikman, J. M. (2011). Late specialization: the key to success in centimeters, grams, or seconds (cgs) sports. *Scandinavian Journal of Medicine & Science in Sports, 21*(6), e282-e290. 10.1111/j.1600-0838.2010.01280.x

Molden, D. C., & Dweck, C. S. (2006). Finding" meaning" in psychology: a lay theories approach to self-regulation, social perception, and social development. *American Psychologist, 61*(3), 192.

Montgomery, H. E., World, M., Thomas, E. L., Brynes, A. E., Saeed, N., Barnard, M., Bell, J. D., Prasad, K., Rayson, M., Talmud, P. J., Humphries, S. E., Marshall, R., Hemingway, H., Myerson, S., Clarkson, P., Dollery, C., Hayward, M., Holliman, D. E., & Jubb, M. (1998). Human gene for physical performance. *Nature, 393*(6682), 221-222. 10.1038/30374

Mujika, I., & Padilla, S. (2001). Physiological and performance characteristics of male professional road cyclists. *Sports Medicine, 31*(7), 479-487.

Myer, G. D., Jayanthi, N., DiFiori, J. P., Faigenbaum, A. D., Kiefer, A. W., Logerstedt, D., & Micheli, L. J. (2016). Sports specialization, part II: alternative solutions to early sport specialization in youth athletes. *Sports Health, 8*(1), 65-73.

Neisser, U., Boodoo, G., Bouchard Jr, T. J., Boykin, A. W., Brody, N., Ceci, S. J., Halpern, D. F., Loehlin, J. C., Perloff, R., & Sternberg, R. J. (1996). Intelligence: knowns and unknowns. *American Psychologist, 51*(2), 77.

Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 1-55). Lawrence Erlbaum Associates.

Norman, D. A., & Bobrow, D. G. (1975). *On data-limited and resource-limited processes*. Elsevier Inc. 10.1016/0010-0285(75)90004-3

Paton, C. D., & Hopkins, W. G. (2001). Tests of cycling performance. *Sports Medicine, 31*(7), 489-496.

Paunescu, M., Gagea, G., Paunescu, C., Pitigoi, G., & Elisabeta, E. (2013). Relationship Between General Intelligence and Motor Skills Learning Specific to Combat Sports. *Procedia - Social and Behavioral Sciences, 84*, 728-732. 10.1016/j.sbspro.2013.06.635

Payne, T. W., & Smith, G. (2014). INSPECTION TIME FOR VERBAL STIMULI: LETTER DETECTION, IDENTIFICATION AND DISCRIMINATION SPEED. *Journal of Communications Research, 6*(1)

Penke, L., Denissen, J. J., & Miller, G. F. (2007). The evolutionary genetics of personality. *European Journal of Personality: Published for the European Association of Personality Psychology, 21*(5), 549-587.

Pennington Biomedical Research Centre. (2013). *The Heritage Family Study*. Retrieved 02/15 2013, from http://www.pbrc.edu/heritage/index.html

Planinsec, J. (2002a). Developmental changes of the relations between motor performance and fluid intelligence. *Studia Psychologica, 44*(2), 85-94.

Planinsec, J. (2002b). Relations between the motor and cognitive dimensions of preschool girls and boys. *Perceptual and Motor Skills, 94*(2), 415-423. 10.2466/pms.2002.94.2.415

Plomin, R., & Deary, I. J. (2015). Genetics and intelligence differences: five special findings. *Molecular Psychiatry, 20*(1), 98-108. 10.1038/mp.2014.105

Plomin, R., & Spinath, F. M. (2004). Intelligence: Genetics, Genes, and Genomics. *Journal of Personality and Social Psychology, 86*(1), 112-129. 10.1037/0022-3514.86.1.112

Pocock, C., Dicks, M., Thelwell, R. C., Chapman, M., & Barker, J. B. (2019). Using an imagery intervention to train visual exploratory activity in elite academy football players. *Journal of Applied Sport Psychology, 31*(2), 218-234.

Polderman, T. J., Benyamin, B., De Leeuw, C. A., Sullivan, P. F., Van Bochoven, A., Visscher, P. M., & Posthuma, D. (2015). Meta-analysis of the heritability of human traits based on fifty years of twin studies. *Nature Genetics, 47*(7), 702-709.

Power of, 1. 0. (n.d.). *Athlete's lookup.* . Retrieved January 18th 2013, from http://www.thepowerof10.info/athletes/athleteslookup.aspx

Rascle, O., Charrier, M., Higgins, N., Rees, T., Coffee, P., Le Foll, D., & Cabagno, G. (2019). Being one of us: Translating expertise into performance benefits following perceived failure. *Psychology of Sport and Exercise, 43*, 105-113.

Raven, J. (2003). Raven progressive matrices. *Handbook of nonverbal assessment* (pp. 223-237). Springer.

Rees, T., Hardy, L., Güllich, A., Abernethy, B., Côté, J., Woodman, T., Montgomery, H., Laing, S., & Warr, C. (2016). The Great British Medalists Project: A Review of Current

Knowledge on the Development of the World's Best Sporting Talent. *Sports Medicine, 46*(8), 1041-1058. 10.1007/s40279-016-0476-2

Rhodes, S. D., Bowie, D. A., & Hergenrather, K. C. (2003). Collecting Behavioural Data Using the World Wide Web: Considerations for Researchers. *Journal of Epidemiology and Community Health (1979-), 57*(1), 68-73. 10.1136/jech.57.1.68

Rivera-Brown, A. M., & Frontera, W. R. (2012). Principles of exercise physiology: responses to acute exercise and long-term adaptations to training. *Pm&r, 4*(11), 797-804.

Rutherford, S. L. (2000). From genotype to phenotype: buffering mechanisms and the storage of genetic information. *Bioessays, 22*(12), 1095-1105.

Savage, J. E., Jansen, P. R., Stringer, S., Watanabe, K., Bryois, J., De Leeuw, C. A., Nagel, M., Awasthi, S., Barr, P. B., & Coleman, J. R. (2018). Genome-wide association meta-analysis in 269,867 individuals identifies new genetic and functional links to intelligence. *Nature Genetics, 50*(7), 912-919.

Scharfen, H., & Memmert, D. (2019). Measurement of cognitive functions in experts and elite athletes: A meta-analytic review. *Applied Cognitive Psychology, 33*(5), 843-860.

Scharfen, H., & Memmert, D. (2019). The relationship between cognitive functions and sport-specific motor skills in elite youth soccer players. *Frontiers in Psychology, 10*, 817.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84*(1), 1-66. 10.1037/0033-295X.84.1.1

Scott, J. P. (1986). Critical periods in organizational process. In F. Falkner and J.M. Tanner (Ed.), *Human Growth. Vol. 1. Developmental Biology, Prenatal Growth.* (pp. 181-196.). Plenum Press.

Seidler, R. D., Bo, J., & Anguera, J. A. (2012). Neurocognitive contributions to motor skill learning: the role of working memory. *Journal of Motor Behavior, 44*(6), 445-453. 10.1080/00222895.2012.672348

Serrien, D. J., Ivry, R. B., & Swinnen, S. P. (2007). The missing link between action and cognition. *Progress in Neurobiology, 82*(2), 95-107.

Shiffrin, R. M., & Schneider, W. (1977). *Controlled and Automatic Human Information Processing: 11. Perceptual Learning, Automatic Attending, and a General Theory*

Simon, H. A., & Chase, W. G. (1973). Skill in Chess. *American Scientist, 61*(4), 394-403.

Simonton, D. K. (1999a). *Origins of genius: Darwinian perspectives on creativity*. Oxford University Press.

Simonton, D. K. (1999b). Talent and Its Development: An Emergenic and Epigenetic Model. *Psychological Review, 106*(3), 435-457. 10.1037/0033-295X.106.3.435

Smith, S. R. (2001). The social construction of talent: a defence of justice as reciprocity. *Journal of Political Philosophy, 9*(1), 19-37.

Smits-Engelsman, B., & Hill, E. L. (2012). The relationship between motor coordination and intelligence across the IQ range. *Pediatrics, 130*(4), e950.

Spearman, C. (1904). "General Intelligence," Objectively Determined and Measured. *The American Journal of Psychology, 15*(2), 201-292.

Staff, T., Gobet, F., & Parton, A. (2020). Investigating the Period of Practice Needed to Acquire Expertise in Great Britain 2012 Track and Field Olympic Athletes.

Staff, T., Gobet, F., & Parton, A. (2021). Early Specialization and Critical Periods in Acquiring Expertise: A Comparison of Traditional Versus Detection Talent Identification in Team GB Cycling at London 2012. *Journal of Motor Learning and Development.,* https://doi.org/10.1123/jmld.2020-0039.

Starkes, J. L., Deakin, J. M., Allard, F., Hodges, N. J., & Hayes, A. (1996). Deliberate practice in sports: What is it anyway? In K. A. Ericsson (Ed.), *The road to excellence: The acquisition of expert performance in arts, sciences, sports, and games.* (pp. 81-106). Lawrence Erlbaum Associates, Inc.

Streiner, D. L., & Norman, G. R. (1995). *Health measurement scales, 2nd ed. A practical guide to their development and use, Oxford:* . Oxford University Press.

Strel, J. (1996). *An analysis of the development trends of motor abilities and morphological characteristics and their relations with psychological and socialogical dimensions of Slovenian children and youth.* (). Ljubljaja: Fakulteta za sport:

Sullivan, A. M. (1964). *The relationship between intelligence and transfer.*

Sun, P. (1986). A Study on the Intelligence Level of P.E. Students Specializing in Soccer, Basketball and Volleyball. *China Sport Science, 3*, 56-58.

Svetlov, P. G. (1972). Ontogenesis as a purposeful (teleonomic) process. *Arkhiv Anatomii, Gistologii i Embriologii, 63*(8), 5-16.

Swann, C. (2016). Flow in sport. *Flow experience* (pp. 51-64). Springer.

Taatgen, N. A., Lebiere, C., & Anderson, J. R. (2006). Modeling paradigms in ACT-R. In R. Sun (Ed.), *Cognition and Multi-Agent Interaction: From Cognitive Modelling to Social Simulation.* (pp. 29-52). Cambridge University Press.

Telegraph. (n.d.). *Team GB Olympic athlete profiles.* Retrieved January 18th 2013, from http://www.telegraph.co.uk/sport/olympics/Team-GB/competitors/

Terborg, J. R. (1977). Validation and extension of an individual differences model of work performance. *Organizational Behavior and Human Performance, 18*(1), 188-216. 10.1016/0030-5073(77)90028-9

Tiberiu, P., Mihai, B., Cristian, N., Nicoleta, M. S., Cerasela, D., Martin, D., Adrian, N., & Eugen, B. (2020). Is the Strength Training a Key for Performance in Cycling?–A Case

Study. Paper presented at the *6th International Conference of Universitaria Consortium "FEFSTIM: Physical Education, Sports and Kinesiotherapy–implications in Quality of Life"*. 31.

Tucker, R., & Collins, M. (2012). What makes champions? A review of the relative contribution of genes and training to sporting success. *British Journal of Sports Medicine, 46*(8), 555-561. 10.1136/bjsports-2011-090548

Tukey, J. W. (1977). *Exploratory data analysis*. Addison Wesley.

U.K. Sport. (n.d.(a)). *Talent Identification & Development.* Retrieved 07/02 2013, from http://www.uksport.gov.uk/pages/talent-id/

U.K. Sport. (n.d.(b)). *Talent 2016: Tall and talented.* Retrieved 02/15 2013, from http://www.uksport.gov.uk/pages/talent-2016-tall-and-talented

U.K. Sport. (n.d.(c)). *Power2Podium.* Retrieved 07/06 2013, from http://www.uksport.gov.uk/news/power2podium-hopefuls-put-through-their-paces-at-loughborough-university-201011

Ullén, F., Hambrick, D. Z., & Mosing, M. A. (2016). Rethinking expertise: A multifactorial gene-environment interaction model of expert performance. *Psychological Bulletin, 142*(4), 427-446. 10.1037/bul0000033

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. (2005). An automated version of the operation span task. *Behavior Research Methods, 37*(3), 498-505. 10.3758/BF03192720

Vaeyens, R., Güllich, A., Warr, C. R., & Philippaerts, R. (2009). Talent identification and promotion programmes of Olympic athletes. *Journal of Sports Sciences, 27*(13), 1367-1380. 10.1080/02640410903110974

van der Fels, I. M. J., te Wierike, S. C. M., Hartman, E., Elferink-Gemser, M. T., Smith, J., & Visscher, C. (2015). The relationship between motor skills and cognitive skills in 4–

16 year old typically developing children: A systematic review. *Journal of Science and Medicine in Sport, 18*(6), 697-703. 10.1016/j.jsams.2014.09.007

Van Raalte, J. L., Vincent, A., & Brewer, B. W. (2016). Self-talk: Review and sport-specific model. *Psychology of Sport and Exercise, 22*, 139-148.

Vazire, S., & Gosling, S. D. (2004). e-Perceptions: Personality Impressions Based on Personal Websites. *Journal of Personality and Social Psychology, 87*(1), 123-132. 10.1037/0022-3514.87.1.123

Verburgh, L., Scherder, E. J., van Lange, P. A., & Oosterlaan, J. (2014). Executive functioning in highly talented soccer players. *PloS One, 9*(3), e91254.

Verburgh, L., Scherder, E. J., Van Lange, P. A., & Oosterlaan, J. (2016). Do elite and amateur soccer players outperform non-athletes on neurocognitive functioning? A study among 8-12 year old children. *PLoS One, 11*(12), e0165741.

Vestberg, T., Reinebo, G., Maurex, L., Ingvar, M., & Petrovic, P. (2017). Core executive functions are associated with success in young elite soccer players. *PloS One, 12*(2), e0170845.

Vickers, D., Nettelbeck, T., & Willson, R. J. (1972). Perceptual indices of performance: The measurement of 'inspection time' and 'noise' in the visual system. *Perception, 1*(3), 263-295.

Vickers, D., & Smith, P. L. (1986). The rationale for the inspection time index. *7*(5), 609-623. doi: *Personality and Individual Differences, 7*(5), 609-623. 10.1016/0191-8869(86)90030-9

Viru, A., Loko, J., Harro, M., Volver, A., Laaneots, L., & Viru, M. (1999). Critical periods in the development of performance capacity during childhood and adolescence. *European Journal of Physical Education, 4*(1), 75-119.

Viteles, M. S. (1933). The influence of training on motor test performances. *Journal of Experimental Psychology, 16*(4), 556.

Voss, M. W., Kramer, A. F., Basak, C., Prakash, R. S., & Roberts, B. (2010). Are expert athletes 'expert'in the cognitive laboratory? A meta-analytic review of cognition and sport expertise. *Applied Cognitive Psychology, 24*(6), 812-826.

Vroom, V. H. (1964). *Work and motivation*. Wiley.

Wai, J. (2014). Experts are born, then made: Combining prospective and retrospective longitudinal data shows that cognitive ability matters. *Intelligence, 45*(1), 74-80. 10.1016/j.intell.2013.08.009

Ward, P., Hodges, N.J., Williams, A.M. & Starkes, J. (2007). The road to excellence in soccer: a quasi-longitudinal approach to deliberate practice. *High Ability Studies, 18*, 119-153.

Wassenberg, R., Vles, J. S. H., Feron, F. J. M., Kessels, A. G. H., Hendriksen, J. G. M., Kalff, A. C., Kroes, M., Hurks, P. P. M., Beeren, M., & Jolles, J. (2005). Relation Between Cognitive and Motor Performance in 5- to 6-Year-Old Children: Results From a Large-Scale Cross-Sectional Study. *Child Development, 76*(5), 1092-1103. 10.1111/j.1467-8624.2005.00899.x

Wattbike. (2010). *An introduction to the Wattbike.* Retrieved 07/13 2013, from http://youtu.be/i6cCcB1jorY

Wechsler, D. (1981). *Manual for the Wechsler Adult Intelligence Scale-Revised.* Psychology Corporation.

Weedon, M. N., & Frayling, T. M. (2008). Reaching new heights: insights into the genetics of human stature. *Trends in Genetics, 24*(12), 595-603. 10.1016/j.tig.2008.09.006

Wein, H. (1973). *The science of hockey*. Transatlantic Arts.

Werdelin, A. T., & Stjernberg, G. (1969). On the nature of the perceptual speed factor. *Scandinavian Journal of Psychology, 10*, 185-192.

Whiting, H. T. A. (1969). *Acquiring ball skill: a psychological interpretation*. Bell.

Wildman, R., Kerksick, C., & Campbell, B. (2010). Carbohydrates, physical training, and sport performance. *Strength & Conditioning Journal, 32*(1), 21-29.

Williams, A. M. (2000). Perceptual skill in soccer: Implications for talent identification and development. *Journal of Sports Sciences, 18*(9), 737-750.

Williams, A. M., & Ericsson, K. A. (2008). From the Guest Editors: How Do Experts Learn? *Journal of Sport & Exercise Psychology, 30*(6), 653-662.

Williams, A. M., & Ford, P. R. (2009). Promoting a skills-based agenda in Olympic sports: the role of skill-acquisition specialists. *Journal of Sports Sciences, 27*(13), 1381-1392. 10.1080/02640410902874737

Williams, A. M., & Reilly, T. (2000). Talent identification and development in soccer. *Journal of Sports Sciences, 18*(9), 657-667. 10.1080/02640410050120041

Williams, A. M., & Jackson, R. C. (2019). Anticipation in sport: Fifty years on, what have we learned and what research still needs to be undertaken? *Psychology of Sport and Exercise, 42*, 16-24.

Wissler, C. (1901). Correlation of mental and physical tests. *Psychological Review Monograph, 16*

Wolff, W., Bieleke, M., Stähler, J., & Schüler, J. (2021). Too bored for sports? Adaptive and less-adaptive latent personality profiles for exercise behavior. *Psychology of Sport and Exercise, 53*, 101851.

Wright, M., De Geus, E., Ando, J., Luciano, M., Posthuma, D., Ono, Y., Hansell, N., Van Baal, C., Hiraishi, K., & Hasegawa, T. (2001). Genetics of cognition: outline of a collaborative twin study. *Twin Research and Human Genetics, 4*(1), 48-56.

Wu, S. K., Chiang, C., Song, T., Liew, E., & Chen, W. (2019). Correlations between perceptual and motor performance tests in elite table tennis players. *Journal of Exercise, Movement, and Sport (SCAPPS Refereed Abstracts Repository), 51*(1), 71.

Yang, H., & Fu, J. (1998). Study on guards intelliogence structure of Chinese womens basketball team A. *Journal of Nanjing Institute of Physical Education, 2*(4), 60-63.

Yang, N., MacArthur, D. G., Gulbin, J. P., Hahn, A. G., Beggs, A. H., Easteal, S., & North, K. (2003). ACTN3 Genotype Is Associated with Human Elite Athletic Performance. *The American Journal of Human Genetics, 73*(3), 627-631. 10.1086/377590

Young, B. W., & Salmela, J. H. (2002). Perceptions of training and deliberate practice of middle distance runners. *International Journal of Sport Psychology, 33*(2), 167-181.

Young, R. M. (2001). *Production Systems in Cognitive Psychology.* Retrieved 2014, from http://www0.cs.ucl.ac.uk/staff/r.m.young/publications/00.PS-encyc-article.pdf

Yustres, I., Santos del Cerro, J., Martín, R., González-Mohíno, F., Logan, O., & González-Ravé, J. M. (2019). Influence of early specialization in world-ranked swimmers and general patterns to success. *PloS One, 14*(6), e0218601.

Zhang, L. W. (1994). Preliminary Study on the Intelligence of Chinese Table Tennis Players. *Sport Science, 6*, 34-39.

Zhu, P. l., & Fang, X. C. (1988). **Intelligence of master sportsmen in Shanghai**. *Acta Psychologica Sinica, 20*(23), 61-68.