The Role of General Motor Ability and Agility in Sport Performance

by

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Abstract

The concept and assessment of general motor ability (GMA) has declined in favour of specialisation and training specificity in athlete development (AD). Early specialisation and a focus on specificity have increased the physical and psychological loading on athletes entering formal development structures or programmes. As a consequence, the use of generic movement training and the use of GMA has significantly decreased. It is suggested that this may be creating athletes who are less adaptable and resilient, with regards to learning new motor skills, transferring skills, and potentially being more prone to injury. Accordingly, the role of general motor ability in sports performance remains unclear, and there is a lack of research which examines its' potential in facilitating improvement in performance. Alongside the diminished role of GMA, there is obfuscation on the role agility plays in AD. The concept of agility is currently constrained by an overly simplistic interpretation that limits it to reactive directional changes. Developing a novel construct of agility, where it can offer both generic and specific qualities, may support the operationalisation of GMA in contemporary AD programmes. In doing so, this may also help to balance the impact of early specialisation and training specificity. Founded on this rationale the objectives of this thesis were as follows:

1. To provide an overview of GMA and agility, including a reinterpretation of the agility construct.
2. To establish the importance of GMA in AD by examining the association between GMA, physical attributes and technical playing attributes in youth RL players.
3. To explore the mechanisms which may underpin GMA.

4. To investigate the development of GMA and explore the nature of longitudinal changes in GMA between youth RL players and youth school children.
5. To explore the role of GMA in acute skill transfer and describe its role in facilitating athlete resilience and adaptability in motor skill learning.

Addressing the first objective Chapter Two provides a critical overview of GMA and agility in sports performance and AD; specifically reviewing the conceptualisation of GMA and presenting a reinterpretation of the agility construct. The second and third objectives were met using the context of Rugby League (RL). The correlational study in Chapter Three used 33 junior RL players to establish the importance of GMA, concerning the positive relationship with physical and technical playing attributes. In Chapter Four, correlational and predictive analysis on tests of GMA, generic and specific agility on 107 junior RL players were used to explore the mechanisms which may underpin GMA. Importantly, GMA had excellent predictive abilities on the performance of generic and specific agility movements. The results of an analysis of specific kinematic variables of preplanned and reactive change of direction (CoD) tasks suggested movement variability was important in these CoD tasks. Objective four was achieved by employing a quasi-experimental design, 36 youths drawn from two groups were pre and post tested on measures of GMA, generic and specific agility to assess the impact of a generic agility intervention and a physical education (PE) curriculum. GMA is not static; training status and varied practice influence its level. In addressing the final objective, Chapter Six used multilevel modelling to examine the clustering of data on six repeated trials on a novel task in high and low GMA groups. Thirty eight students were assessed for GMA and the evolution of their novel task performance. Better GMA performers were able to outperform participants with low GMA on the novel task; findings being indicative of better skill transfer. In conclusion, the five studies aimed to provide a significant contribution to the scientific knowledge. GMA, operationalised through generic agility, does relate to sport-specific performance. Better GMA relates to enhanced performance on a complex and novel CoD task. While GMA is in a state of flux and can be improved by various types of physical activity (PA). Further research into the specific nature of generic agility training, for performance and health, to help sustain motor competence and reduce injury is recommended.

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AD	Athlete development
CoD	Change of direction
CoD_{pp}	Preplanned change of direction
CoD_r	Reactive change of direction
CoD step	Step at which CoD occurs
CoM	Centre of mass
CRoP	Coaches' rating of performance
$Decel_1$	Average deceleration during the first CoD in the novel task
$Decel_2$	Average deceleration during the second CoD in the novel task
EHC	Eye-hand coordination
ES	Effect size
FMS	Fundamental Movement Skills
GMA	General motor ability
GMA_H	Higher GMA group
GMA_L	Lower GMA group
MV	Movement variability
NMT	Neuromuscular training
PA	Physical activity
PE	Physical Education
PL	Physical Literacy
pre-CoD step	Step prior to the CoD step
PT	Performance time
$PVel_1$	Peak velocity prior to the first CoD in the novel task
$PVel_2$	Peak velocity prior to the second CoD in the novel task
RFL	Rugby Football League
RL	Rugby League
WMAT	Western Motor Ability Test

Chapter One

Introduction

1.1 The Impact of Specialisation and Specificity in Athlete Development

With the increased commercialisation of sport, there is a greater potential to be employed professionally or semi-professionally and this is becoming a realistic occupation for advanced performers. This new environment has been reflected in the improved standard of the training processes, people and structures that support professionalisation. A scientific approach to developing these support systems has also become normal (Sanctuary, Meir, & Sadler, 2012), for example AD programmes that are founded on research-informed evidence-based practice (Collins & MacNamara, 2018). In an attempt to increase the productivity of AD programmes there has also been an increase in specific training methods and approaches (Santos, Mateus, Sampaio, & Leite, 2017). There has undoubtedly been an increase in specialisation (Myer et al., 2015, 2016) and a greater emphasis on the use of specificity in sports training (Giboin, Gruber, & Kramer, 2015). Specialisation refers to the long-term focus on a single sport while excluding all other sports through a structured development programme (Jayanthi & Dugas, 2017). This tendency to focus and specialise on a single sport seems to be based on the logic of *more is better*, or that increased targeted training over an extended period will produce a better-specialised athlete who attains expert status earlier or faster (Baker, Horton, Robertson-Wilson, & Wall, 2003; Collins et al., 2012). This specialisation can be related to the notion of deliberate practice (Baker, Cote, & Abernethy, 2003) and the use of 10 years as a requirement to achieve expert status (Ericsson, Krampe, & Tesch-Römer, 1993), both of which are common in applied practice. If specialisation relates to intense training in a single sport, specificity can be considered the limited transfer of motor competence of physical attributes between movement and skills (O’Keeffe, Harrison, & Smyth, 2007; Young, McDowell, &

Scarlett, 2001). Mastery of specific skills is a vital determinant of everyday tasks as well as in the performance outcome of many sports. The development of motor coordination in specific movement patterns, meaningful tasks, and techniques form a crucial part in the long-term conditioning of an athlete and in maintaining their health and wellbeing. While the development of these specific skills is underpinned and supported by an entire vocabulary of sub-components of more basic movement patterns for example Fundamental Movement Skills (FMS) (Kirk & Rhodes, 2011), the recognition and importance of GMA is somewhat underplayed with regards to improving sports performance and promoting lifelong PA. Therefore, counterbalancing this shift towards specialisation and movement specificity with GMA, through recognising the benefits of generic movement training and acknowledging the role of skill transfer of generalised movement competencies into sport-specific contexts are keys aims of this thesis.

Contemporary research examining the relationship between specialisation, specificity of training and GMA is uncommon. However, research investigating the relationship between the early broader sampling of sport and subsequent specialisation is more prevalent (e.g., Fransen et al., 2012). For example, Güllich (2018) hypothesised three processes to explain the positive interaction of sports specialisation and broader sampling, and these were (a) sustainability (b) multiple sampling and functional matching and (c) learning transfer as preparation for future learning. Sustainability to indicate the enduring selection of a specific sport following sampling a broad range of activities, functional matching describing an authentic and rationalised selection process an individual undergoes in selecting a sport to specialise in, and the adaptability or transfer of movement competences founded on participation in varied activities. It is this adaptability, built on a broad sampling of sports, which resonates with the aims of this thesis.

The notion of this thesis and its context originates from having been a practitioner, working in several sports, for more than 20 years; where I have supported youth athletes in elite development environments. Broadly, I have worked with scholarship and academy Rugby League (RL) players as a professional strength and conditioning coach. Throughout this extended period, I have developed my ideas around AD, which included a holistic approach to the development of players, competency in FMS and specifically focusses upon the establishment and ongoing improvement in general athleticism. This athleticism, I believe, underpins and better enables the development of sport specific skills and attributes, a central tenant of this work. Whilst merely anecdotal evidence, I have, over this time, acknowledged a change over time in young people's ability to competently and proficiently perform non-complex human movement patterns or FMS and how these issues impact the development of more advanced skills. For example, how their underpinning movement competency influences their progress in learning new skills or facilities the transfer of skill.

Accordingly, in my role as a practitioner working with developing athletes, I have established a philosophy to support my approach to AD. This philosophy aims to develop and promote physically capable individuals who are adaptable, skilful, coachable and who in due course can perform at the highest level. It is underpinned by athleticism or good GMA (Fleishman, 1964; Hands, McIntyre, & Parker, 2018), which supports essential sport-specific development in athletic performance. In contrast the increasing focus upon sport-specific abilities and performance at the expense of exploring a more diverse and general movement competency or GMA in developing athlete's performance has reduced the adaptability and resilience of athletes. It has also led to an increasing number of athletes being selected onto AD programmes or progressing to secondary education who have experience in specialised sports while having very poor FMS and poor development of their neuromuscular system (O' Brien, Belton, & Issartel, 2016). These poor attributes manifest themselves as poor movement mechanics, lower ability to efficiently learn and adapt motor skills (Clark & Metcalfe, 2002), less resilience to training load and poorer ability to transfer motor competence (cf. Collins et al., 2012; Jess & Collins, 2003). These deficits may be summarised as these athletes having poor athleticism in applied sport-specific situations.

It is the emergence of a developmental philosophy in AD and its application in my professional work, which was the impetus for this thesis, to provide an evidence base on which future applied practice may be established. Therefore this thesis has revisited the role of GMA in sports performance, investigating the associations between GMA, physical attributes, skilled performance and characteristics that are key to sporting performance (Delextrat, Grosgeorge, & Bieuzen, 2015; Gabbett, Kelly, & Pezet, 2007; Giles, 2007; Scanlan, Humphries, Tucker, & Dalbo, 2014). While GMA is not a new concept, in assessing and developing athletes in AD programmes it has fallen out of fashion; while there continues to be an increasing focus on the benefits of specificity in training and early specialisation.

The process of learning motor skills is essential in sports performance (Archer, Drysdale, & Bradley, 2016; Browne, 2009; Hirano & Funase, 2017; Magill, 2001; Schmidt & Lee, 2014; Thompson & Wolpaw, 2014). Understanding these processes helps us to appreciate the role of GMA in developing athletes. Advanced motor competencies of an individual are constructed upon elements of coordination, functional strength, motor integration, spatial awareness, segmental interaction and rhythm (Barnett, Stodden, et al., 2016), which can be considered as the basic building blocks (i.e., the *words*) on which we develop FMS, our movement literacy (the *sentences*, e.g., walking, running, jumping, and throwing); and then upon which specific complex movement patterns are created (the *story*; Giles, 2007). Clark and Metcalfe (2002) described the importance of general motor abilities stating, “build a sufficiently diverse motor repertoire that will allow for later learning of adaptive, skilled actions that can be flexibly tailored to different and specific movement contexts” (p. 176). The dynamic nature of interacting coordination elements may be described as *rate limiters* (Abbott et al., 2007) and through specific training may cause non-linear development of overall performance supported by a well-developed *base* (Hulteen, Morgan, Barnett, Stodden, & Lubans, 2018). It is hypothesised therefore that maintaining a broad range of general motor skills, represented by GMA may have a vital role in facilitating the interaction of these supportive factors in creating sophisticated and specific movement patterns.

1.2 GMA, Agility and AD

Agility has been identified as having a significant influence on sports performance (Lockie, 2013; Sheppard & Young, 2006). It has been defined as the ability to brake, change direction and accelerate (Plisk, 2000). Agility seemingly incorporates and represents many FMS (Balyi & Hamilton, 2004), and coordinative elements that a performer requires for learning and developing complex motor skills. The extent to which agility as a holistic construct has been explored is limited, as is its potential as a training modality for operationalising GMA. Therefore, in this thesis I revisited the role of agility and its link with GMA in sports performance. How emerging GMA can be operationalised through the development and training of agility. While examining this interpretation of agility in training and developing athletes I explored a new definition of agility that supports both specific and general components. Establishing a base of GMA through developing both general and specific components of agility may have several beneficial effects including a reduction in injury risk, improvement in the performance of sport-specific skills and facilitate the learning and relearning of skills.

A measure of the usefulness of GMA is the capacity of a performer to learn a new skill, as a performer develops co-ordinated motor skills, they will include higher levels of sophistication in more complex sequences, and this may be perceived as general motor competences with added layers of sophistication. Therefore, having a good range and quality of building blocks is beneficial in this process to enable and facilitate transfer from general to specific motor skills. Alternatively, are general and specific motor abilities separate entities, thus explaining the authentic examples observed in applied practice, that of the individuals who can perform higher level co-ordinated movements but become motorically challenged when asked to undertake simple tasks that are novel to them? The contemporary shift in the importance of specificity has led to much confusion and debate in applied practice, with what could perhaps be an obfuscating misinterpretation of agility development leading to the recent focus on a high degree of sports specificity in agility training.

As an example research has demonstrated the impact of the specificity of training on the development of sport-specific movement patterns (Haugen, Tønnessen, Hisdal, & Seiler, 2014; Moradi, Movahedi, & Salehi, 2014; Young et al., 2001). Previously, research has suggested that linear sprint training appears to have little or no influence on the improvement of sprinting that involves changes of direction (Young et al., 2001). This weak relationship between linear sprinting performance and change of direction speed performance (Baker, 1999; Buttifant, Graham, & Cross, 1999; Clark, Martin, Lee, Fornasiero, & Quinn, 1998; Tsitskarsis, Theoharopoulus, & Garefis, 2003; Young, Hawken, & McDonald, 1996) has been proposed as evidence for the need for training specificity. Contrary to this it has been suggested that enhancing generalised and fundamental physical attributes will empower and contribute to sport-specific performance to some extent (Hammami, Negra, Shephard, & Chelly, 2017; Santos et al., 2017). Harre (1982) stated the transfer of motor abilities from conditioning tasks to specific movement patterns inevitably would lead to successful performance.

Therefore, the proposed role for a new agility construct, that is better developed and maintained generalised agility directly supports specific agility, is central to my thesis. I suggest that a general agility programme may have a vital role in promoting the ability to transfer skill from a general to a specific movement in lower level athletes or younger individuals. Such generic training may also play a role, both directly and indirectly, in enhancing the self-efficacy of these individuals as they try, and hopefully succeed at, at an ever-greater range of sports and PA. More necessarily I also suggest that maintaining a general agility base in more established athletes will enhance sport and context-specific skills.

1.2.1 Robustness and injury.

GMA may have a function in the pre-habilitation of athletes, for example, the chronic effect of incorporating FMS training and Neuromuscular Training (NMT) may help minimise the risk of injury in training and competition (Kiefer & Myer, 2015). This on-going training effect coupled with improved technical and mechanical ability may improve skill-based performance and cause a reduction in tissue stress (Kiely, 2017). This effect is particularly significant in those established athletes who are highly skilled and therefore need to be protected as valuable assets. In the unfortunate occurrence of injury, there may also be a rehabilitating effect of agility on recovery. Neuroscience may offer a mechanism which helps us understand how this general agility could work. The concept of neural plasticity (Jenkins & Merzenich, 1987) describes the ability of the central nervous system to adapt and change in an on-going process that is almost limitless. This type of learning and relearning, the construction of neural maps to establish and update co-ordinated movement patterns (Avanzino et al., 2014), movement variability in avoiding tissue stress (Seifert, Button, & Davids, 2013), efficiency and status of motor modules to build coordinated sophisticated skills (Hirano & Funase, 2017) seems to fit the supporting role GMA may have.

1.3 Objectives of the Thesis

In this thesis I hope to re-examine a broader concept of agility, redefining it from its more traditional perspective, and highlight the importance of GMA in developing specific agility in performers (Bailey et al., 2010; Drost & Todorovich, 2013). Accordingly, the thesis aims to address gaps in the scientific understanding of GMA and agility with specific objectives set out as follows:

1. To provide an overview of GMA and agility, including a reinterpretation of the agility construct.
2. To establish the importance of GMA in AD by examining the association between GMA, physical attributes and technical playing attributes in youth RL players.
3. To explore the mechanisms which may underpin GMA.
4. To investigate the development of GMA and explore the nature of longitudinal changes in GMA between youth RL players and youth school children.
5. To explore the role of GMA in acute skill transfer and describe its role in facilitating athlete resilience and adaptability in motor skill learning.

The current lack of appreciation for generality is concerning, as a focus on GMA may confer a variety of advantages to both developing and established performers. The nurturing of and focus upon a more significant base of generic problem-solving capacities facilitates the ability to coordinate and blend many contributing sub-capacities or fundamental elements into existing and novel movement solutions for higher order skills and more sport-specific movement complexes (cf. Barnett et al., 2016). This *twin-track* approach to developing sports performance in both generic and specific movements seems sensible, attending to the specific requirements of a sports skill, while also enhancing and maintaining the foundations on which they are built.

The starting point is to provide an overview of GMA. What might it be?

Chapter Two

What might it be? An overview of GMA

2.1 Introduction

Debate around the existence and relative importance of GMA continues, notwithstanding the weight of historical perspectives on both sides of the debate. Despite the contemporary shift, in AD and applied practice, away from generalised training to a focus on sports specificity (Scanlan et al., 2016; Young & Farrow, 2013), I hypothesised that there was merit in re-examining the role of GMA, to benefit AD and talent identification.

Previous work by Henry (1968) and Fleishman (1964) highlighted the importance and need for sports specificity in training and athlete preparation. This research reported the importance of sports specificity, stating that precise movement patterns and techniques are essential to sports performance. It did not, however, acknowledge the parallel importance of maintaining a broad movement literacy, which provides the foundations and attributes for sports specificity and facilitates the developing competency of performers. GMA may represent this movement literacy and reflect a specific mix of motor abilities (Ibrahim, 2009) which underpin AD, helping to establish a broad and general base of motor ability. To support the re-invention and re-deployment of developing GMA as a training construct, a reinterpretation of the agility construct is required. For example, the role of generic agility may be to operationalise and maintain GMA, which in turns supports more specific performance. Therefore to begin, I present an historical review of the GMA construct including the various debates associated with it. The intention is to frame the narrative of GMA and present a discussion supporting its revival in contemporary AD before highlighting the role of a reinterpreted agility construct.

2.2 Historical Perspective

2.2.1 Early development of the GMA concept.

The existence of GMA and how it has been conceptually interpreted is a recurring theme in the literature (Fleishman, 1964; Campbell & Tucker, 1967; Magill, 1993, 2001; Burton & Miller, 1998). Recent research has highlighted evidence for such a concept, suggesting that GMA remains contemporary and necessary (Ibrahim, Hear, & Blanksby, 2011; Hands et al., 2018). A traditional definition of GMA is “a trait of an individual that underlies the performance of all movement skills” (Burton & Rodgerson, 2001 p. 348), this being based upon the proposed definition by Schmidt & Lee (1999). GMA has also been referred to as motor ability, athletic ability, athleticism (Hands et al., 2018) or simply, coordination (Schmidt, 2011). While some (Ellison, Kearney, Sparks, Murphy, & Marchant, 2017) have questioned the concept of generality and have championed a more task-specific approach to motor assessment. Historically, this has led to the notion that assessing GMA, or other interpretations of it, has been useful in identifying talent for sports performance (Fleishman, 1958b, 1964). This has led to the availability of numerous assessment tools such as the Western Motor Ability Test (Campbell & Tucker, 1967) and the Bruininks-Oseretsky Test of Motor Proficiency (Bruininks, 1978). Some of which are not explicitly designed to evaluate GMA, but rather, were designed to assess underlying motor and physical abilities. The issue of assessing GMA, and the impact this has had on acknowledging its importance, is covered in Section 3.1.2 of this thesis.

Notwithstanding the issue in GMA assessment, in a recent paper by Ellison et al. (2017) examining the effectiveness of contemporary commercial Eye-Hand Coordination (EHC) devices, provided further evidence against EHC as a GMA. Indeed, it was suggested that practitioners should “explore sport-specific assessment and training of EHC” (p. 6). Ellison et al. (2017), thereby highlighted the shift in a concept that has long historical roots. The conclusions by Ellison et al. (2017) are also an explicit representation of the ongoing and extended debate as to the relative importance of sports specificity, generalisation of movement development and skill transfer in AD. These specific issues are reviewed in more detail later in the chapter.

Early research in the twentieth century into the GMA construct gained prominence, with the development of several tests which targeted the objective assessment of generalised motor abilities. Sargent and McCloy's work are examples of research that promoted the notion of general underlying abilities which could be used to predict or associate performance in more skilled movements. Sargent (1921) developed his *jumping* test, describing it as a useful and straightforward test of physical ability; although today described as primarily a test of leg power, this may be one of the earliest examples of using a simple test to link fundamental physical abilities in more complexed or skilled movements. McCloy's (1932) work evaluated the correlates of the Sargent's jump with tests of athletic motor abilities and demonstrated relationships that would be described as strong or moderate. For example, McCloy stated "the correlation of track and field athletics (four events equally weighted and scored on the author's scoring tables) with Sargent jump was .752" (1932 p. 239).

McCloy (1934) went on to develop his test of GMA and test of motor capacity. This is so that, as well as having a measure of underlying GMA, by assessing motor capacity, an assessment of General Motor Achievement Quotient could be estimated. Therefore, McCloy's assessment represents an individual's potential to achieve based upon standard scores. Further early examples of how assessments of GMA were used to globally evaluate the physical competence of individuals and groups include Cozens' (1928) research on general athletic ability or physical efficiency in college students. Using a battery of tests and computing a composite score, individuals could be classified on their weaknesses which could be targeted for further development. In this test there was also differentiation made within student cohorts, based on overall assessments, to allow for better students not being *held back* (Cozens, 1928).

2.2.2 The development of movement taxonomies.

In a more contemporary review of the GMA construct, Burton and Rodgerson (2001) stated:

> "We assert that an assessment instrument that produces composite scores for groups of related movement tasks can be considered to be a test of motor abilities or GMA when the interpretations of the scores are intended to extend beyond the specific skills included in the assessment or, in other words, are generalised beyond the skills assessed" (p. 353).

Burton and Rodgerson went on to support this perspective with the proposal of a new taxonomy to help frame motor development. They described a system with four key factors: movements skills, movement skill sets, movement foundations and GMA. Though developed from previous models, the innovation here primarily focussed on a reinterpretation of motor abilities, with movement skill sets and movement foundations. Although it is clear that they maintained a base in their taxonomy featuring an underlying GMA, though it is highlighted that GMA is not in itself a movement skill or movement set. Namely, it is a quality, or the summation of numerous sub-capacities, which can be drawn upon to improve movement skill efficiency. Fleishman (1964, 1972) did identify 11 psychomotor abilities (multilimb coordination, control precision, response orientation, reaction time, rate control, manual dexterity, finger dexterity, arm-hand steadiness, wrist finger speed, aiming and speed of limb movement) and nine physical attributes (static strength, dynamic strength, explosive strength, trunk strength, gross body coordination, gross body equilibrium, stamina, extent flexibility and dynamic flexibility), that represented a single motor ability, for example, coordination, movement precision, and response orientation, as well as strength and dynamic flexibility (Hands, et al., 2018). Figure 2.1 assists the visualisation of three levels (skills) of Burton and Rodgerson's taxonomy, and how they interrelate. Hop, gallop and horizontal jump skills are underpinned by common movement skill foundations (MSF), such as: balance/postural control, body composition, cognition, flexibility/range of motion, motivation and affect and muscular strength and endurance. These MSF combine in each specific skill in varying way to influence, either facilitating or constraining the outcome of each particular skill; this is indicated by the shading of the MSF in Figure 2.1. In this model, GMA could be perceived as forming a bottom layer of the structure upon which the rest of the MSFs and skills are founded and built.

In contrast to this positive approach to the GMA construct, Henry (1968) when commenting upon his previous work, stated that it was inappropriate to continue to consider unitary abilities and that gross motor abilities were specific and required appropriately specific practice to develop. These ideas of weak relationships between underlying general motor abilities and skilled movements, along with suggestions for applied specific practice, was summarily incorporated in his specificity hypothesis. This hypothesis has been cited in research to justify the treatment of underlying abilities as distinct and unrelated to each other (e.g., Ellison et al., 2017; Giboin et al., 2015; Jeffreys, 2011; Thomas & French, 1985), and perhaps has been the inspiration for task specificity and its focus in more contemporary work (Moradi et al., 2014), seemingly reducing the impact of more *general* motor ability. This is in agreement with Marteniuk (1974) who concluded that common factors or abilities cannot explain the performance relationship between the progression from simple to complex motor task. Burton and Rodgerson (2001) disputed Marteniuk's interpretation of correlation coefficients and therefore his conclusions, stating that a limit of 50% variance was too constrained in allowing smaller coefficient to be dismissed as unimportant. Recently Hands et al. (2018) also examined the issue related to low correlations between factors supporting the justification of decrying a GMA, they suggest the arbitrary choice of variables to be assessed and variation in analytical tools as some reasons why these poor relationships have been previously found. For example, Ellison et al. (2017) directed practitioners to employ more sport-specific assessment when examining the transfer of assessment scores between assessment devices. Explicitly, while exploring the correlations between EHC assessment devices, they concluded that the relationships were mostly weak. This interpretation, however, may be misguided in the context of Burton and Rogerson's representation of GMA. Though low intercorrelations were found in the Ellison et al. study, between four separate devices, they measured EHC via a variety of different techniques. Therefore, each device may be measuring movement skill sets and underlying movement skill foundations that are fundamentally different. Consideration should be given to factors affecting correlation size, and therefore the implications of setting arbitrary *cut-off values*. Goodwin and Leech (2006) presented six factors that influence the size and interpretation of *r* values, these were "(a) the amount of variability in either variable, X or Y; (b) differences in the shapes of the two distributions, X or Y; (c) lack of linearity in the relationship between X and Y; (d) the presence of one or more "outliers" in the dataset; (e) characteristics of the sample used for the calculation of the correlation; and (f) measurement error" (p.252). For example, low variability in data sets may results in lower r values, this may be interpreted as indicating a weak relationship while a lower cut-off would be more appropriate.

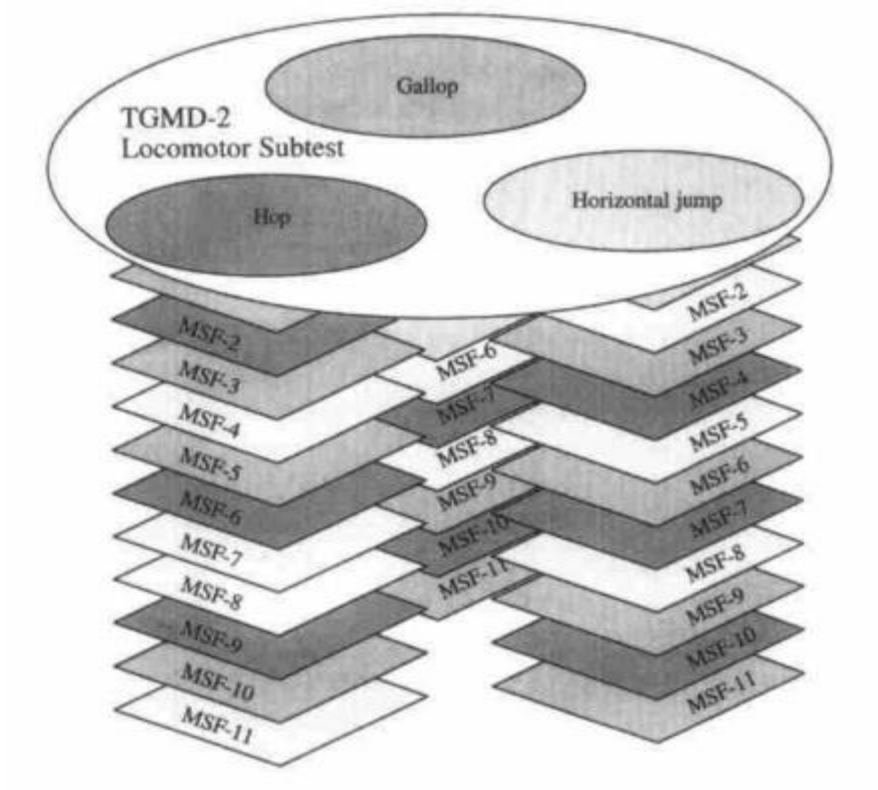

Figure 2.1. Adapted from Burton & Rodgerson (2001), using three movements skills from the Test of Gross Motor Development (TGMD-2, Ulrich, 2000). The model represents how common MSF (n=11) impact each movement skill to varying extent.

Previously these low correlation coefficients, suggestive of weak relationships between physical and motor abilities, have been used as a justification for dismissing the existence of GMA or stating that these various physical and motor abilities are different components and should be developed separately (Sever, Arslanoğlu, & Arslanoğlu, 2016). “In the context of general intelligence, however, correlation coefficients between .40 to .50 are recognised as suggesting higher order or general factors” (Burton & Rodgerson, 2001, p.349). Ibrahim et al. (2011) claimed that low correlations merely indicate that there is a weaker relationship between factors relating to GMA and are not compelling evidence that GMA does not exist.

2.2.3 The importance of movement specificity.

While some have defined levels of movement skills, movement sets, and GMA, Henry (1968), for example, has disputed the conceptual notion of GMA. Research has indicated a relationship with particular motor abilities and motor or movement skills (Young & Farrow, 2013). Namely, those specific skills are supported and underpinned by specific abilities; however, these abilities are unrelated. Fleishman (1958a), while examining psychomotor performances, concluded that performance on a variety of positioning tasks had a high degree of specificity; and the predictive value of one task on another was weak. These conclusions are in agreement with Schmidt and Lee (2011) who commented on the correlational predictions of GMA, those underlying abilities should be highly related, whereas examples exist where this is not the case (Bachman, 1961, Fleishman, 1964). Though low correlations between abilities may indicate they are mutually exclusive (Whitely, 1983), this does not bar them from separately supporting a higher goal, or their influence in forming the foundations of movement skill or motor movement sets. This is similar to the concept of *components of fitness* (Dick, 2014), that identifies physical components which represent underlying physical mechanisms. Specific physical attributes may be grounded in very different physiological processes, for example, the flexibility of a performer, developed through adaptation within connective tissue, is very different to their aerobic capacity, as a function of cardiac output, mitochondrial density. Both these valuable components still collectively effect the economy in, for example, a running gait. Factor analytical studies, based upon the employment of a factor analysis (Schmidt & Lee 2011), have provided an approach that may also provide some support. Somewhere between acknowledging GMA and the broad clustering or identification of related factors that underpin higher-order movement skills, there may be a definite link. Through the use of research in ability tests and assessments, groups of related abilities have been recognised and evidenced, such as multi-limb coordination, movement orientation and reaction time. These factors have been extensively mapped and identified as specific and distinct areas of physical and motor competence; however, do we end up moving to the same place, common underlying factors? This could also be perceived as another interpretation of global abilities underpinning higher order sport-specific skills but highlights the issue that these different interpretations might be a semantics, cultural appropriation, or personal perspective.

2.2.4 Motoric *g*.

One discursive point which may be critical in how GMA is operationalised or re-interpreted surrounds the notion of whether there is a singular GMA or multiple general motor abilities. Burton and Rodgerson (2001) implied that there is one GMA, which underpins movement skills foundations, whereas other interpretations suggest that groups of more general motor abilities may exist (Magill, 2001). Such differing interpretations may not be helpful in appreciating the benefits and concepts of GMA and whether it exist but do deserve to be explored and perhaps re-interpreted.

Ibrahim et al. (2011) investigated the use of a motor skills task (Australian Institute of Sport Talent Identification Test (AIST, Australian Sports Commission, 1998) and a Balance and Movement Coordination Test (Ibrahim, 2009). They identified a motoric *g*, this higher-order *g* is described as representing a GMA. Consistent with other interpretations of GMA, Ibrahim et al. (2011) described the motoric *g* as representing the general aptitude of an individual in motor ability, underpinning foundational movements and specific skills. Separately, Larkin, Hands, Parker, Kendall, and Sloan (2007), used component analysis and concluded that specific motor abilities, as represented by their respective first-order factors for the boys and girls, were embodied by the concept of this higher order motoric *g*; as such indicating that general motor abilities do exist. Although the Larkin et al. (2007) data falls short of providing conclusive proof of a singular GMA, the suggestion by Burton and Rodgerson (2001) that groups of specific motor abilities or movement set/foundations underpin skilled movements goes a long way to recognising the importance of general traits in sport-specific performances.

Hands et al. (2018) have very recently revisited the GMA concept, identifying several decisive advantages of this theoretical stance. That is, it unifies a diverse approach to motor development; secondly, any valid assessment of GMA would support the prediction of performance and development, and finally, GMA would help inform the development of training practices. Hands et al. presented tenets of their model that include, (a) GMA being a unidimensional construct which reflects the ability to perform and learn motor skills, and (b) GMA is a representation of performance on a variety of motor skills underpinned by general motor learning and not by specific motor abilities. A critical point that Hands et al. presented described GMA as a *fluid entity*, it is proposed that GMA is not a fixed quality but is developmental and progressive across a lifespan.

Despite the evidence, some being somewhat dated, and the continued use of such fundamental motoric tools in assessing athletic potential (Tribolet, Bennett, Watsford, & Fransen, 2018), there is limited research into the applicability of GMA in more contemporary AD programmes. For example, as a training aid or training modality, how might the ongoing rehearsal of general motor abilities support sport-specific performance? Training GMA might be operationalised through movement diversification and general movement challenges. The value in revisiting this balanced approach to motor skill development, focusing on general as well as the specific, may be reflected in its potential to support an applied practice. To consider the importance of GMA, to practitioners, I have examined the agility construct. What follows is an exploration of the nature of agility and how it might be re-interpreted to include the development of GMA.

2.3 The Agility Construct

The importance of agility has been acknowledged as a critical contributor to sporting success (e.g., Chelladurai, 1976; Arshi, Nabavi, Mehdizadeh, & Davids, 2015; Spasic, Krolo, Zenic, Delextrat, & Sekulic, 2015; Nimphius, Callaghan, Bezodis, & Lockie, 2018), particularly in team sports (Paul, Gabbett, & Nassis, 2016) and in the development of elite performers. As such many practitioners and researchers have attempted to highlight discrete co-ordination elements that may signpost future performance through its use. However, agility as a term is often used in connection with many components of psychomotor performance without a sufficiently specific understanding of how it applies; therefore, the extent and nature of this contribution remains clouded. There is a case for the development of agility to improve sports performance, however, the benefits of any transfer of simple, general motor skill elements in influencing specific movement patterns are by and large assumed. Currently, the agility construct lacks a precise and universally accepted definition (Čoh et al., 2018; Young, Dawson, & Henry, 2015) and there seems to be an insufficiency of sensitive quantification tools (Nimphius et al., 2018). The absence of a coherent conceptual framework contributes to a sense that, although all agree that agility is essential, it is not clear what exactly it is. Nor is there clarity on how it may be measured, how it may be optimally developed and most crucially, how it may ultimately contribute to long-term performance objectives.

Despite research into agility being popular (Delextrat et al., 2015; Dos'Santos, Thomas, Comfort, & Jones, 2018; T. Gabbett & Benton, 2009; Lockie, Dawes, & Jones, 2018; Matlák, Tihanyi, & Rácz, 2016; Nimphius et al., 2018; Oliver & Meyers, 2009; Sassi et al., 2009; Serpell, Ford, & Young, 2010; Wheeler & Sayers, 2010; Warren, Young & Willey, 2010), contemporary interest in it as a holistic concept remains low, specifically there is a lack of clarity on how more general agility should be developed, trained and assessed (Young & Farrow, 2006) to enhance AD. Despite the historical context of GMA discussed in Section 2.2, the focus on engendering, maintaining and enhancing agility has seemingly diminished within many contemporary sports performance programmes. This reduction may be due to a range of conspiring factors, such as new systemic pressures, poorly construed performance models and ever younger sports-specific specialisation (Sugimoto, Stracciolini, Dawkins, Meehan, & Micheli, 2017). This has led to practices in talent development that have marginalised the role of generic agility. The manifestation of this may be seen in the impact of early specialisation on reducing the exposure of young athletes to a variety of sporting activities (cf. Mostafavifar, Best, & Myer, 2013). In this chapter, in contrast to contemporary trends, I outline a rationale proposing that this decreased focus on generic agility represents an oversight, which may ultimately compromise the performance potential of athletes. I begin by clarifying my interpretation of the agility construct; outline the critical components underpinning agile, athletic performance and finally propose how long-term generic agility training may provide players with performance and injury resilience benefits.

2.3.1 What is agility?

Agility is a crucial dimension of skilled performance (Lockie et al., 2013; Paul et al., 2016; Sheppard & Young, 2006) and is a valued physical capacity, acknowledged by coaches and academics alike as a vital component of athletic success in many sports. However, there appears to be a degree of ambiguity on how the term agility is used in different sporting communities. Is it an athlete's reactive ability, their capacity to change direction at speed, or merely another term for task-specific movement competency? By contrast, in applied practice agility is a commonly used term, often associated with those better performers who seem to have the ability to *evade capture* on a pitch, demonstrate high levels of *coordination* or create *outrageous* positions on a court; exhibiting greater levels of dynamic control over ballistic movements in response to dynamically changing events (Serpell et al., 2010).

A curious aspect of agility is that, despite the term's ubiquity in everyday sporting vernacular, the broader more overarching view of agility is somewhat out of fashion, with the construct remaining inadequately empirically explored, and incompletely theoretically defined or grounded. Indeed, recent decades have seen any priority on general agility focused activities diminished by an increasing shift towards early sports specialisation (Wiersma, 2000; Christianson & Deutsch, 2012), and an associated increase in sports-specific movement skill development (Lloyd & Oliver, 2012), as opposed to more generic, agility-based movements (Bailey et al., 2010). This contemporary shift has led to much confusion and debate in applied practice, with what could perhaps be seen as an obfuscating misinterpretation of agility development leading to a focus on high sports specificity in agility training.

Agility is an essential attribute of many movement skills and movement skill sets and has been described as incorporating the ability to change speed and direction while competently maintaining balance, power, and coordination (Arshi et al., 2015). Various definitions are offered within the literature, ranging from the broad (e.g., "the efficiency of movement throughout the entire kinetic chain regardless of the skill being executed", Giles, Penfold, & Giorgi, 2005 cited in Giles, 2007, p. 9), to the more specific, (e.g., the ability to maintain or control body position while quickly changing direction during a series of movements (Twist & Benickly, 1996) and minimising the loss of speed whilst maintaining body control under conditions of deceleration, change direction and acceleration (Graham, 2000)). Other definitions are even more explicit in focusing uniquely on the perceptual and cognitive components of agility, acknowledging that changes in direction are commonly undertaken in response to external stimuli (e.g., Benvenuti, Minganti, Condello, Capranica, & Tessitore, 2010; Young & Willey, 2010). Indeed, Paul et al. (2016) used the word agility to exclusively describe a perceptual decision-making process in response to a stimulus. These cognitive abilities have been described as the defining factors in agility performance, though the underlying mechanisms involved are less well understood.

While such definitions are seductive in their clarity, things are often more complicated than suggested. Movements may be forceful, may variously require movement through an extended range of motion, and involve complex limb-to-limb or eye-to-limb coordination, and yet not necessarily fit with the conventional definitions of agile behaviour presented above. An important characteristic of the practical coaching perception of agility, which has thus far eluded articulation within single-sentence definitions, is that agile behaviours are too often perceived as being executed solely at the very edge of motor capabilities. Consequently, I suggest that agility should be conceived as describing movement solutions which require the dynamic integration of several sub-capacities and FMS[1] in some complex and challenging permutation to satisfy the demands imposed by a rapidly changing physical context. It may therefore be posited that a wide range of contributing sub-capacities and FMS enables agile behaviour. Furthermore, when executing any agility task, some of these sub-capacities and FMS should be extensively challenged. Definitively, these sub capacities may include, but not be limited to, forceful and powerful muscular multi-joint contractions (Zatsiorsky, 2002), capable stretch-shortening cycles (Bissas, Cooke, Paradisis, & Liefeith, 1996; Kraemer & Looney, 2012), neurological competency in perceptual motor integration, and can be summarised as coordinative ability. Therefore these sub capacities may be interpreted as a sophisticated and well developed neuromuscular system built upon FMS (Naclerio & Faigenbaum, 2011). Barnett, Stodden, et al. (2016) also included “contralateral coordinative functioning of extremities,…optimal relative

[1] The use of FMS in this thesis, although aligned to the typical interpretation, may also extend to the contemporary interpretation of foundational movement skills in Hulteen et al. (2018) model, where a broader non-typical range of movement skills are also included. For example, overhead pressing, squatting and lunging.

timing of segmental interactions,…and optimal inter and intramuscular coordination and optimal transfer of energy through the kinetic chain" (p. 221), in their list of sub-capacities, or *fundamentals* of coordination and control, which support FMS. Alongside these sub-capacities, FMS are an essential feature of the interpretation of generic agility and form a crucial part to operationalising generic agility. Therefore, difficult movement challenges such as work to extend your motor competence, develop new motor skills or to recover from injury are all inherently and unavoidably facilitated by high levels of generic agility enabled by engagement in FMS. For clarity motor competence in this thesis may be defined as "the acquisition and refinement of skillful performance in a variety of movement activities that straddle the biological and behavioral domains" (Malina, 2014, p. 158).

FMS and generic agility

FMS can be summarised as locomotive, manipulative, non-manipulative skills, for example walking and running (locomotive), throwing and catching (manipulative), and balance and body orientation (non-manipulative) (Chen, Hammond-Bennett, & Hypnar, 2017). They include such movement qualities as mobility, dexterity, speed, postural control, perceptual awareness, reflexive decision making, power etc. Pichardo, Oliver, Harrison, Maulder, and Lloyd (2018) highlighted "the importance of FMS development prior to more complex non-specific training methods (e.g., plyometric and strength training)… and should be included throughout development due to links with athletic motor skills and long-term effects of physical activity" (p. 8). Whereas, Ford et al. (2011) described the theoretical underpinning for FMS development in children and youths, explaining the research which describes the developmental process of motor learning. Ford et al. summarised the support for "enhanced neural and muscular adaptations (due to the plasticity of the neuromuscular system) through exposure to regular and structured fundamental movement skills and fundamental sports skills training in childhood.” (p. 393), but do not go as far as highlighting this approach in youths or adults. The importance of acknowledging the role that plasticity of the neural system in this motor development process (see Section 2.5.1), should be mentioned, the contemporary view of lifelong neuroplasticity may support and rationalise the ongoing maintenance of FMS to ensure the competency of general motor attributes to bolster skill learning and development. Correspondingly, Clark, Barnes, Holton, Summers, & Stratton, (2016) noted that quantity of activity in FMS was in itself not the best measure of developing movement competency, it was the evaluation of difference in FMS could potentially better reflect quality. In a coaching setting, this might indicate a focus on movement quality as much as engaging in FMS would help support the development of motor learning.

In this thesis, FMS, underpinned by the sub-capacities detailed above, can be seen to be aligned and be representative of generic agility. It is therefore assumed that reference to engaging in or utilising generic agility is associated with the development of FMS and the associated fundamentals of coordination and control.

Exploring agility as an overarching and superordinate quality

The nature of encountered movement problems and thus, the agility demands placed upon a performer, vary extensively depending upon sporting context. The agility of the cross-country runner, the triple jumper, the rock-climber and the table-tennis player are all, in executional terms, very different. At a generalised level, it also seems apparent that a common set of underpinning capacities ultimately enables agile behaviour. Consider, for example, Giblin, Collins, MacNamara, and Kiely (2014) and MacNamara, Collins and Giblin (2015) on the essential nature of basic (generic) agility for subsequent development of (specific) skill. Giblin et al. (2014) identified that adequate movement skills underpin several factors impacting PA, ranging from routine daily tasks to elite-level sports performance. Importantly, such generic skills underpin the athlete's ability to meet any variability in a sporting challenge. This requirement is evident in games players, where the level of variability in the demands of play is extensive. Even closed sports skills hold significant variability in their challenges, for example, varied wind, run-ups or take off dynamics in the triple jump. Furthermore, variation is required of the athlete through changes associated with many factors, such as growth, training, ageing, and injury. In short, athletes have an inherent need to handle variable challenges, and I suggest, generic agility provides the equipment necessary to meet this challenge (cf. Chapter Four).

Thus, agility may be considered an abstract, overarching and superordinate capacity, enabled by the coordinated blending of numerous contributing sub-capacities. I refer to abstract in the sense that it is these sub-capacities, physical entities or biological processes, which combine to create a specific movement output, while agility is the abstract concept that encompasses these components. Therefore, the development of agility should surely be an essential feature at every stage of an athlete's development. To fulfil these various roles, the agility construct may be conceptualised as having both generic and specific components. The generic characterised by an ability to efficiently negotiate a diversity of movement challenges, underpinned by a range of well-developed sub-capacities. The specific characterised by an ability to more quickly and accurately solve the narrower sub-set of movement problems commonly posed within a particular sporting context. Building on the ideas expressed above, I present an argument that both generic and specific elements of agility performance should be consistently emphasised within long-term performance training programmes. However, before this, I present the case that current, *en vogue*, AD models or programmes may curtail the generic agility base essential to subsequent development.

2.4 Why Has Generic Agility Training Diminished?

The root of this diminishing use of generic agility may, at least in part, lay with the AD processes currently in common usage. Over the course of recent decades, many sporting cultures have embraced early-specialisation models (Smith, 2015; Torres, 2015). The trend within AD being to recruit future performers at progressively younger ages, thereby extending exposure to learning experiences focused upon optimising future sport-specific performance (Myer et al., 2016). Although issues related to such AD models have been acknowledged previously (e.g., Bailey & Collins, 2013; Ford et al., 2011), it is pertinent to highlight the historical and contemporary impact of these AD models on the development and maintenance of generic agility.

Early focus and subsequently increased volume of context-specific learning experiences within AD programmes have undoubtedly contributed to ever-increasing levels of task-specific performance in many domains. However, there remains lingering doubt as to the universal applicability of early-specialisation dogma. In our eagerness to imprint sports-specific capacities on ever-younger performers, perhaps to fulfil misguided short-term agendas (Collins et al., 2012), are the potential benefits bestowed by certain generic capacities being overlooked, undermined and under-developed? Is an early focus on sports-specific agility, resulting in a reduced focus on generic agility, a developmental strategy which ultimately promotes, or inhibits, optimised long-term sporting performance?

A related point is a pervading idea that sports-specific performance is always best served by extensive, sports-specific practice (cf. Ericsson et al., 1993). For example, a defining characteristic of some published AD models (e.g., Long-Term Athlete Development; Balyi & Hamilton, 2004) is the segregation of the overall developmental process into progressive blocks, whereby attributes, capacities and FMS, developed in preceding stages are utilised, and capitalised upon, in subsequent periods. The rationale here is that specific stages of chronological maturity accompany specific *windows of opportunity*, i.e., critical periods which provide a unique opportunity to embed specific athletic characteristics. It is suggested that if appropriate training stimuli are not imposed within the timeframe presented by such windows, then the opportunity for targeted development, is either completely lost, or severely diminished (Balyi & Hamiliton, 2004). This conclusion is seemingly not supported by the previous literature. Bailey et al. (2010) highlighted that, although there may be plausible benefits in identifying periods of time where greater improvements may occur, there remains a lack of population-specific evidence to support this. Baker, Côté, and Abernethy (2003) also identified that expert decision-makers in team sports specialised relatively late, having first experienced an extensive base of sporting experiences in their earlier years. Similarly, the Balyi position has been previously questioned from a physiological perspective (Ford et al., 2011) with regards to specific windows of physical development. Ford et al. (2011) suggested the Long-Term Athlete Development model lacks empirical evidence to support it. Specifically, that there is poor evidence supporting the idea that not maximising physiological adaptation in these critical windows of opportunity would have a negative effect and would produce a ceiling effect as to an individual's development.

2.4.1 Example of sports specificity.

The importance of specificity is not being questioned in this thesis, however, its relationship with generality and the potential of GMA to counterbalance specialisation and specificity is. It therefore noteworthy to highlight an example where specificity in movement skill development has been established and is the norm in the coaching of performers. Can the experience of these individual sports demonstrate the benefits of this sport-specific skills approach and counter the foundational approach of developing GMA, to support key performance criterion? Gymnastics has a well-established tradition of focussing on improving movement skills by performing gymnastic specific skills. In other words, the way performance is developed is through rehearsal and repetition of the *competition-moves* themselves. It is only recently there are more examples of gymnastics using additional or non-traditional training modalities to support skill progression; for example, strength and conditioning sessions involving external loading using weight training movements (Sands, McNeal, Jemnic, & Delong, 2000). It could be interpreted that this approach, i.e., blending of sport-specific training and more general motor development, could marry the positives of both modalities; to the ultimate benefit of the long-term athlete's development.

Accordingly, broad experience seems to be functionally beneficial, both developmentally, for longer-term attainment of sports performance and lifelong engagement in PA. Indeed, Bailey and Collins (2013) highlight research (cf. Polman, Walsh, Bloomfield, & Nesti, 2004) suggesting that, while it might be productive to develop FMS during early childhood, it is not exclusive to this time frame as these skills can be continually developed into adulthood. Unfortunately, in my view, many sport governing bodies have prematurely applied AD systems, or the equally challenged pyramid approach (Bailey & Collins, 2013), with each sport vying for talented youngsters to enter pathways before the proposed ‘critical periods' terminate.

2.4.2 The potential role of GMA in AD models.

The structural framework offered by AD models provides an apparently user-friendly and attractively simple long-term planning template for governing bodies, sporting institutions, and the coaches of young athletes. Although the primary assumption of AD philosophy may be eminently sensible, i.e., elite development requires extensive dedication of time and focused effort, there are a number of associated secondary assumptions, offered as substantiation for appropriate AD guidelines, which appear less rationally justifiable.

Potentially and notably contradictory to other elements of this approach, established AD doctrine has also emphasised the importance of the early creation of

FMS, collectively defined as locomotive, manipulative and stabilisation skills (Lubans, Morgan, Cliff, Barnett, & Okely, 2010), on which the subsequent development of higher level skills are supported (Balyi & Hamiliton, 2004). Accordingly, the importance of early exposure to a broad range of movement skills, and the associated development of a broad spectrum of fundamental movement patterns is frequently cited as a necessary condition for the advancement of higher-order patterns (Berry, Abernethy, & Côté, 2008; MacNamara et al., 2015). However, although AD models provide, at least superficially, a rational template upon which to base long-term AD strategies, three questions remain as to how these proposed developmental philosophies impact upon athletic agility. Firstly, while the importance of a broad movement base has been emphasised within early developmental training phases, many models seem to ignore the need for such an explicit emphasis (cf. Giblin et al., 2014), or assume that this Physical Literacy (PL) base can be accomplished through unstructured play (MacNamara et al., 2015). "Physical literacy can be described as the motivation, confidence, physical competence, knowledge and understanding to value and take responsibility for engagement in physical activities for life." (Whitehead, 2006, p. 127). In this chapter, I use the term focused on the elements of physical competence, although the other aspects are important and interrelated. Importantly, although never really examined as a specific issue, many authors seem to accept the importance of PL (cf. Chapter Five) or even gloss over it, whilst not considering the ways in which it should be addressed and developed (cf. Giblin et al., 2014; Giblin, Collins, & Button 2014; MacNamara et al., 2015). As a result, the essential base is often neglected or underdeveloped (Burns, Fu, Fang, Hannon, & Brusseau, 2017). Secondly, even when such provision is apparent in the early stages, this generalised movement exposure is often substantially withdrawn in subsequent developmental phases in favour of heavy prioritisation to sports-specific skills (cf. Jess, Collins, & Burwitz, 1998). The related concern being that consistent exposure to generic movement challenges may offer substantial long-term benefits to athletic performance potential (see Chapter Five), which are not necessarily provided through sports-specific movements. Thirdly, much of the philosophy underpinning particular AD models is predicated upon the existence of *critical periods* and *windows of opportunity* for the installation of specific athletic phenotypes (Collins et al., 2012). This reliance on these specific windows of opportunity further exacerbates the trend towards early specialisation, as sports rush to ensure that the supposed benefits of these periods are fully realised. Empirical evidence supporting such assumptions is fundamentally lacking (cf. Ford et al., 2011). Of course, while an absence of evidence is indeed not evidence of absence, if such theories are to claim any form of scientific validity, then the burden of proof surely lies with the proposers of long-term AD theories.

In contrast, a sound evidence-led argument highlights the detrimental consequences of early sports specialisation. As an illustration, recent reviews concluded that there is no evidence that intense training and specialisation before puberty is necessary to achieve elite status, whereas early sports specialisation increases incidence of injury, psychological stress and the likelihood of early deselection from sport (Jayanthi, Pinkham, Dugas, Patrick, & LaBella, 2013; Myer et al., 2015). Consequently, it has been suggested that broad exposure to a wide diversity of movement and physiological challenges is necessary to promote physical resilience and facilitate optimal movement skill development (e.g., Mostafavifar et al., 2013). For example, the National Athletic Trainers' Association recommends that young athletes delay specialisation and participate in multiple sports and recreational activities throughout the year to enhance general fitness and aid motor development (Valovich McLeod et al., 2011). Similarly, a consensus statement of the American Medical Society for Sports Medicine, focused on overuse injuries and psycho-emotional burnout in youth sports, suggesting that a variety of physical and mental health concerns are directly attributable to early sports specialisation (DiFiori et al., 2014). More positively, several sports are increasingly recognising the inherent disadvantages of this approach, especially when considered against the associated risks of early burnout and dropout, and sport-specific overuse injuries (e.g., Bronner, Ojofeitimi, & Rose, 2003; Calhoon & Fry, 1999; Dubravcic-Simunjak, Pecina, Kuipers, Moran & Haspl, 2003; Jayanthi, LaBella, Fischer, Pasulka, & Dugas 2015; Myer et al., 2016; Waldén, Hägglund, & Ekstrand, 2007). The English Rugby Football League is one governing body that has deliberately raised the age of recruitment onto their scholarship system to avoid early specialisation and its associated problems (see also work in Centimetres, Grams or Seconds sports; Moesch, Elbe, Hauge, & Wikman, 2011).

Figure 2.2a is a representation of an interpretation of an existing model of AD. Athletes in these types of structured programmes seem to be entering with a narrower GMA, FMS base or movement skills foundation base, that is less well established or rehearsed. This may be due to inadequate or unstandardised support from the PE curriculum in schools (Giblin et al., 2014; MacNamara et al., 2011; Polman et al., 2004), and less opportunity for young people to play and specialising earlier in one particular sport. While in these programmes they progress, developing a narrow and focused movement skill set (Lloyd & Oliver, 2012: Myer et al., 2016), which potentially may lead to fragile athletes. When challenged outside this narrow skill set the performer regresses because they are reliant upon a poorly established and narrow skills base. Such challenges are inevitable in an athlete’s progression, due to growth, injury or learning new skills (see Chapter Six). I theorised that this current emphasis on early specialisation, as discussed, is restricting the development of young athletes’ FMS and has lasting implication for performance and longevity of a sustained performance career and their wellbeing.

Whereas Figure 2.2b. represents where we should be, athletes should be entering these AD with a broader skills base, supported by better PE. As the athlete develop their specialised skill set, there should be regular enrichment involving diversification of generic skill or FMS to broaden their movement vocabulary.

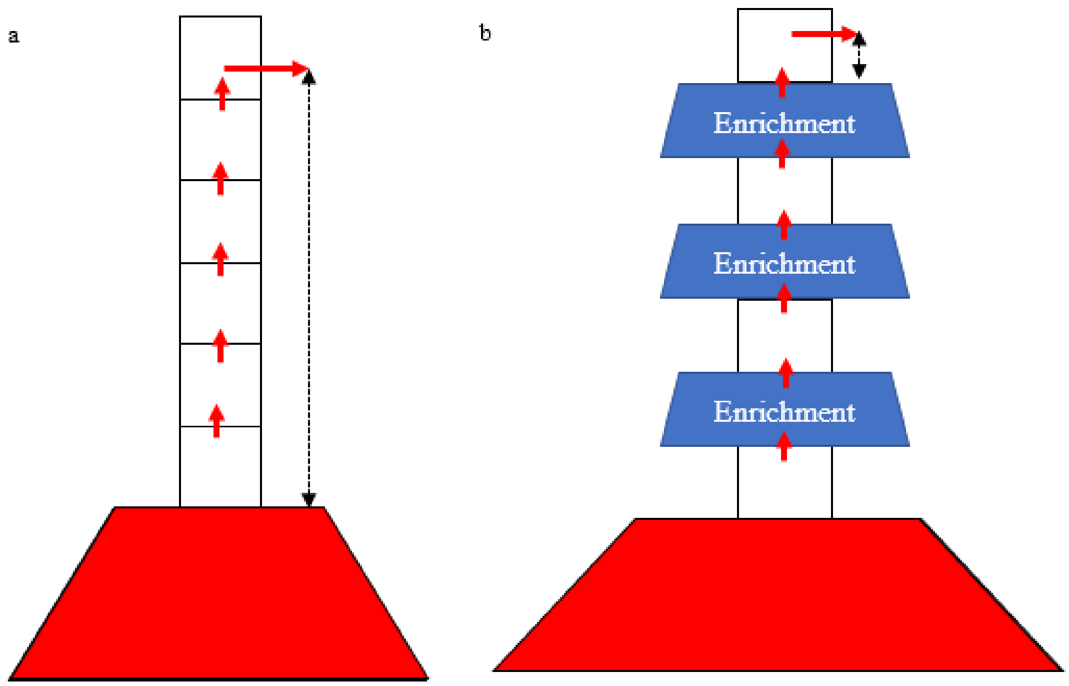

Figure 2.2. Schematics representation of (a) a current AD model and (b) AD model incorporating generic agility (GMA) training. In model a there is a narrow and less extensive base of GMA on which is built a linear and increasingly specialised development programme. While in model b there is a broader and more extensive base of GMA and the specialised development programme is regularly enriched with generic agility and FMS training.

Therefore, challenges outside their usual skill set, such as the athlete going through a growth spurt or injury rehabilitation, can be better managed. Athletes can *fall back* on a more recently rehearsed broader skill set to support current issues. These challenges, such as re-learning motor skills, are therefore better addressed and managed. By increasing the range and developing more generic agility and movement challenges, it would permit the selection from a greater range of physical sub-capacities and FMS in constructing a solution to specific agile behaviours (Wiersma, 2000). The general and specific complement each other and should be perceived, from a training and performance perspective, as integrated. As a specific example, Baker et al. (2003) stated that athletes transition through three stages of sports participation on route to expertise, the sampling years, the specialising years, and the investment years. Each phase has distinct facets, in the sampling years' athletes engage in a wide variety of activities and sports and begin to develop and refine their FMS (running, jumping, and throwing). The specialising years are defined by the channelling of movement skills a more sport-specific context. Finally, in the investment years' athletes reduce sampling and invest time and effort into maximising the performance of a single sport. An approach which promotes a continued and structured training of generic agility to compliment sport-specific skills provides a degree of balance.

To summarise this section, current trends in many sports are typified by ever-earlier recruitment of young talent, in turn leading to early diversion down sports-specific specialisation pathways and, consequently, less resource dedication to generic movement skill development. Consequently, perhaps, specific skill execution in that sport can reach ever higher standards with younger athletes. However, when challenges arise which require skills of a broader, and more generic nature, which are an inevitable feature of sport, performers may lack the breadth of PL needed to overcome them. I consider some of these challenges later. However, first, are these benefits something which is solely a developmental concern with young athletes?

2.5 Factors Underpinning Agility Performance – The Need for Generic and Specific Experience

While a strong argument exists for early generic training, are there equal benefits if this trend is extended into adulthood? I suggest that there are. Effective agility training should promote the emergence of safe and efficient movement solutions to address unique movement problems. The uniqueness in its origin, of each movement problem that may emerge, is because of an ever-varying constellation of underlying factors, both intrinsic (speed, stability, fatigue, body orientation, motivational, etc.) and extrinsic (conditions underfoot, environmental factors, etc.). For example, the subtle magnitude and direction of force application variation required to accommodate wind speed in javelin throwing; or the use of well-established reflexive feedback pathways to accommodate asymmetrical loading in a judo throw.

2.5.1 Motor coordination.

Although the existing formal definitions of agility mostly limits its notion to rapid changes in body position or orientation, this belies the complexity of its component elements and how it is created. These complex interactions of elements which occur in specific sports movement are thought to rely upon the further interaction of several functions in the human body. For example, there is a need to combine physical strength and flexibility, intelligence and motivation as well as balance and motor coordination to provide overall agility. Such a complicated system relies upon the overall management from the neurological system to create successful outcomes in human movement. Dietz (2002) states that a wide range of sources of afferent activity act at several levels within the nervous system to produce functionally integrated patterns of muscle activity. This complexity necessitates an eclectic approach to studies of the function of the nervous system. An area of study concerning this attribute has been termed coordination dynamics. This area defined broadly as the science of coordination (cf. Tschacher & Dauwalder 2003; Jirsa & Kelso 2004). Despite this work, however, Jantzen and Kelso (2007) suggest that coordination, although one of the most fundamental aspects of living things is not well understood. In particular, motor coordination has not been investigated with regards to transfer between levels of development and effect on athletic potential.

In this regard, motor coordination has been linked to several neurological, physiological and mechanical factors. For example, neural processing and the link to intelligence play a crucial role in motor coordination (Planinsec & Pisot, 2006). The co-ordination elements that define whether a movement is a fine or a gross motor skill may influence those elements which define potential in specific sports performance. These may include an eye-hand element, rhythm or the coordination of strength, others to consider are upper and lower extremity coordination and bilateral coordination. These elements may develop an individual's temporal and spatial awareness improves, long-term helping in the construction of sports techniques and overall sports performance.

Schmidt (1975) is one of many who has tried to conceptualise motor learning. He discussed the notion of generalised motor programmes which has relevance to the development of motor coordination from essential elements. However, the theory that people have a GMA, and that this can be used to predict performance across a range of tasks, is not seen as viable (Drowatsky & Zuccato, 1967). But, the use of specific motor programming continues to influence current coaching practice i.e., high sport specificity and an ecological focus on sports practice that is context-specific. Reflecting this apparent contradiction, I have reviewed mechanisms of motor learning in the context of developing agility in sports performance.

Research in neuroscience offers a potential mechanism as to how general agility training may impact higher-order skills and the transfer of skill. Redundancy in the musculoskeletal system has challenged the understanding of how co-ordinated movements occur, arguments being based on the relatively small number of cortical columns in the motor cortex and large numbers of alpha motor neuron pools. This neural issue suggests that there is some mechanism of hard wiring the signals required for specific muscle actions. Motor maps (Neilson & Neilson, 2005) help us understand how this wiring process occurs, in the development of the neural system, to control and coordinate a finite number of elemental movements. The development of motor maps may provide an insight as to how on-going development and practice of general agility may help unpin more specific task dependent movements. Simply put, the consequence of *general motor* agility training may facilitate the construction and refinement of motor maps, a feature which offers an underlying mechanism to the categorical characteristic construct I suggested earlier (see Chapter Six).

Accordingly, regular exposure to a wide diversity of movement challenges can facilitate a thorough exploration of motor-perceptual space. A direct neuro-biological consequence of such expansive movement exploration is that cortical representations of the working musculature become ever-more refined and detailed. This refined motor map, in turn, facilitates more precise neural regulation of muscle activation and thus movement control. A diversity of movement challenge may serve to drive a more precise cortical mapping of the working musculature, leading to an enhanced clarity of neural signal (for a review see, Neilson, & Neilson, 2005). The practical benefits of enhanced mapping are increased precision in timing and regulation of movement forces. Hence, regular exposure to an agility-type diversity of movement challenge may logically facilitate athletes' movement efficiency, their repertoire of potential movement solutions, and their resilience to multiple dimensions of movement stress (Engineer et al., 2012).

The operations of this influence are increasingly acknowledged. PA drives structural plasticity within the motor regions of the brain (e.g., Edgerton & Roy, 2009; Thompson & Wolpaw, 2014). In turn, structural plasticity supports ever-improving communications between neuronal networks whose orchestrated activation facilitates skill development (Kiely, 2017). Such plasticity processes are not confined to the brain, however. Activity-dependent plasticity (Andriyanova & Lanskaia, 2014), driven by the characteristics of descending and peripheral inputs, also shapes neurological micro-architectures, throughout the neural system (e.g., Kiely, 2017). Although spinal adaptations have been less thoroughly investigated than their counterparts in the cortex, the emerging consensus is that they are critical to supporting changes in movement control and coordination (Pelletier, Higgins, & Bourbonnais, 2015). Thus, structural modifications of many forms, from the strengthening of synaptic connections to the thickening of the myelin sheath surrounding neuronal axons, may be unseen, but ultimately underpin a wide range of physical training related performance improvements. It is these pervasive changes, evident at multiple levels throughout the athlete's neurobiological system, which enable the gradual embedding of movement habits and proficiencies. Recently emerged evidence illustrating that such adaptive neuro-plasticity is possible throughout the life-span (e.g., Kleim & Jones, 2008; Merzenich, Van Vleet, & Nahum, 2014) may be particularly relevant to senior athletes who question the potential benefits accruing from generic agility training. Recent evidence suggests that optimally facilitating neuro-plastic processes in mature nervous systems demands that specific fundamental criteria be fulfilled. Precisely, that the movements performed are novel, non-formulaic, relevant and challenging to the athlete (e.g., Avanzino et al., 2014; Engineer et al., 2012); these criteria seemingly overlap with the fundamental descriptors of generic agility movement challenges.

2.5.2 The role of agility in injury rehabilitation.

Neuroscience may again offer a mechanism that helps us understand how generic agility may positively contribute to post-injury rehabilitation processes (Elbert & Rockstroh, 2004). Injury, by standard definition, typically results in the loss of training opportunity for some period. The nature of plasticity within the motor cortex entails that periods of muscular disuse result in a gradual degradation of cortical representations of the inactive muscle (Coq & Barbe, 2011; Pelletier et al., 2015).

Accordingly, sustained periods of disuse are manifest not solely in negative muscular consequences, but also in an increasingly blurred representation of the affected muscular regions within the cortex (Pelletier et al., 2015). Such signalling degradation inevitably leads to a host of adverse movement performance outcomes (Pelletier et al., 2015). A fundamental priority of an active rehabilitation process is the re-configuration of the correspondence between cortical motor maps and the injury-affected musculature (Thompson & Wolpaw, 2014; Wolpaw & Tennissen, 2001). Once more, the process which drives such cortical re-configuration is repeated exposure to novel and varied movement challenges. I therefore suggest that early, and regular, exposure to an appropriately tailored diversity of agility-type movement challenges should be considered a cornerstone of any comprehensive injury rehabilitation protocol.

2.6 Facing Challenges Across the Athlete Lifespan

2.6.1 The role of generic agility in meeting motoric challenges.

As stated earlier, generic movement ability appears to offer the best underpinning preparation for subsequent specific skills (Bailey & Collins, 2013; Berry et al., 2008). There are however, further benefits to building this firm and broad base. What if for example the developing athlete encounters broader movement challenges, i.e., close to or even broader than the specific skill set s/he has built in their sport? Variability in skilled performance has been previously identified in elite performers (Carson, Collins, & Richards, 2014). The variable way a successful performance outcome is achieved can improve the strategies used to cope with internal or external change; that is where adaptability to unexpected perturbations is required (Hiley, Zuevsky, & Yeadon, 2013; Wilson, Simpson, Van Emmerik, & Hamill, 2008). However, is such high variation likely to occur? I contend yes, and that generic agility will offer the PL and skills base to cope in several different but rather common ways. These acute or chronic perturbations may include body changes due to growth spurts

(Cumming, Lloyd, Oliver, Eisenmann, & Malina, 2017), or morphological changes from training effects (Vandendriessche et al., 2012). Changes in the role or playing position of a performer may provoke uncertainty as might the introduction of a new method or approach to technique development. The ongoing refinement of skill may also be influenced by these enforced changes or adaptations, as opposed to mere skill acquisition (Carson & Collins, 2015), highlighting the importance of adaptability and resilience.

2.6.2 The role of agility in movement performance and injury resilience.

The proposed role of agility training in enriching both movement skill acquisition and on-going skill refinement may similarly find application in the nurturing of injury resilience. Generic agility development, whereby a: diversity of muscular-generated and momentum-imposed forces, coordinative patterns, dynamic stabilisation challenges, are experienced at a range of biomechanical positions will engender injury resilience through two mutually intertwined mechanisms. Firstly, through the enhancement of neural, spinal, and neuro-muscular signalling pathways (Pelletier et al., 2015; Thompson & Wolpaw, 2014); and secondly, exposing more musculotendinous tissue to a broader range and extent of loading. These two factors may avoid overuse injuries, by making movements ‘broader' for example. It is important to recognise that these benefits will accrue from an optimum blend of specific and generic agility work; in other words, from movement challenges which are, by turns, closer to (specific) and more diverse than (generic) the target sport.

2.7 Chapter Summary

Based upon the evidence and concepts presented in this chapter I suggest that there is merit in reconsidering the role of GMA as well as generic and specific agility. This re-examination includes how generic agility training may serve multiple potential purposes within high-performance pathways. Regular and persistent exposure to novel movement challenges variously prioritising differing facets of the generic agility construct, offers a more expansive range of performance benefits than is currently appreciated within early specialisation planning philosophies. In closing this chapter, an evidence-led rationale suggests that generic agility training can instil performance benefits which are not provided by exclusively sports-specific training protocols and overly-stringent early specialisation AD models. The benefits of generic agility training may be briefly summarised as:

- Through remediation of chronically overly-habituated dysfunctional movement characteristics, generic agility training may counterbalance early specialisation and sport-specificity, foster skill transfer, improve resilience and reduce the likelihood of injuries
- An on-going diversity of movement challenge creates an optimally fertile neuro-biological environment for continuing re-calibration and refinement of existing sports-specific movement skills

Finally, regular generic agility training facilitates an enhanced dynamic adaptability to cope with movement novelty, hence promoting optimised conditions for both the learning of new skills and the evolution of novel solutions to encountered movement problems. It should be acknowledged that the unique focus on GMA and its relationship with physical attributes, alongside coaches' ratings of performance in RL brings a novel feature to study in this area of research. Therefore, Chapter Three investigated the existence, role and importance of GMA in sport. Specifically, was there a relationship with other factors that have been used to discriminate sports performance.

Chapter Three

Does it Exist? Testing for the Existence, Role, and Importance of GMA in RL

3.1 Introduction

Having made a claim for the general motor construct in Chapter Two, my next aim was to test for the existence and the importance and role of GMA, in the context of other measures of performance, with regards to its role in AD. Therefore, I planned to demonstrate the standing of GMA by assessing its association with vital physical components, valued technical attitudes, and personal characteristics of sport-specific games play. To be clear, it is the recognition of GMA and its potential role in AD that is offered as a novel contribution to scientific knowledge.

As more research is undertaken, and our ability to identify and develop athletic potential improves, the tools and strategies at the disposal of AD personnel, for example, performance directors or strength and conditioning coaches, become more specialised, structured and sophisticated (Lloyd et al., 2015; Lloyd & Oliver, 2012). However, this may have been at the expense of some previously popular concepts, such as GMA, and as a consequence of specialisation reduces motor skill development (Myer et al., 2015). The assessment and application of GMA, in its many varied forms, previously had a central position in supporting the discrimination of athletic performance and athletic potential (see Section 2.2), for both training or selective purposes (Cozens, 1928; McCloy, 1934). Yet, with the focus on specialisation (Mostafavifar et al., 2013; Myer et al., 2015) and deliberate practice (Ericsson et al., 1993) the use of this GMA and general motor assessments have diminished application in contemporary AD programmes (see Chapter Two). The role of GMA to support the identification of talent, its potential role in balancing the impact from early specialisation, and reducing injury risk (Bell et al., 2016), while supporting the development of adaptable athletes (Issurin, 2013) has not been fully explored.

Therefore, in this chapter, I have presented the outcomes of a study examining the associations between GMA, key physical attributes in sporting performance, and the coaches' ratings of characteristics; attributes and characteristics that have been identified as necessary in playing ability. The context in which this was tested was in team games, specifically RL. RL is an invasion game that involves physical contact and as such requires a specific set of skills and physical qualities. Specific physical qualities have been shown to influence gameplay and level of performance in team sports, especially RL (Gabbett, Jenkins, & Abernethy, 2011; Gabbett et al., 2007). For example, Gabbett, Jenkins, & Abernethy (2010) indicated that RL requires high levels of lower body muscular power and acceleration to influence tackling ability.

To help contextualise the importance of GMA I begin with a review of the literature, examining the role of GMA in balancing the effects of specialisation, this review includes GMA's potential association with the perceived importance of physicality and psychosocial characteristics in sports performance, specifically RL. An essential requirement in this study was the selection of an appropriate measure of GMA. Consequently this section also incorporates a review of GMA assessments, highlighting the selection of the Western Motor Ability Test (Campbell & Tucker, 1967) as a simple GMA assessment. Finally, although many contemporary researchers and practitioners dispute the conceptual and applied status of GMA, both the historical and contemporary use of assessments that test for underlying physical and skill attributes remains popular (Lloyd et al., 2016). Particularly in RL, where testing of general qualities, as a part of an applied selective procedure or performance monitoring, is well established (e.g., Gabbett, Georgieff, & Domrow, 2007; Gabbett, Kelly, Ralph, & Driscoll, 2009).

3.1.1 The importance of GMA in counteracting specialisation.

In highlighting the importance of GMA, it is helpful to acknowledge where the perceived benefits of sports specialisation have been derived. The influence of early specialisation and the targeted programming of sport-specific development has its' roots in academic research. For example, the concept of deliberate practice advocated by Ericsson et al. (1993) has had a substantial impact on the development of AD systems; and subsequent influence on specialised training and the perceived benefit of early specialisation (Berry et al., 2008). Ericsson et al. based their requirement of hours spent in deliberate practice as the decisive factor in the development of experts, and as a consequence influenced time spent *on task* in AD programmes. Following on from this, deliberate practice has been conceptualised as the specific focus upon targeted aims of performance as a structured activity and is said to be distinct from other activities such as play, competition, and work (Ford, Ward, Hodges, & Williams, 2009). Consequently, the importance and value of specialisation in AD programmes has been the focus of contemporary research. This research has greatly influenced contemporary applied practice in AD, shifting the focus upon training modalities that are highly specialised, for example, small-sided or modified conditioning games (Carlon, 2012; Chaouachi et al., 2014) for the development of a single sport. In contrast, however, other researchers have developed the notion of deliberate practice and adapted it, demonstrating that expertise can be achieved through a multifaceted approach to deliberate practice (Baker et al., 2003), rather than merely focusing on a single practice environment (Helsen et al., 2000). Baker et al. stated:

> "Accordingly, a more comprehensive understanding of the practice base essential for expert performance, especially team ball sports, requires consideration of not only the sport-specific practice activities undertaken by players but also the nature and extent of practice and experience accumulated in other related activities." (p. 14)

This broader interpretation suggests that the experiences gained from related activities have real value in developing expertise, for example through FMS that can transfer from different activities or sports (Baker et al., 2003). As part of the seven postulates that Côté, Lidor, and Hackfort (2009) presented as being essential to underpin the AD process, their *sampling* concept seems to align with a broader concept of experience to support development, and this relates to developing GMA. That is, multiple abilities developed through involvement in a variety of sports, creating generic movement challenges, provides foundational physical competencies which can be applied in more sport or context-specific environments. However, Côté et al. (2009) model also suggested that the investment in specialised sports training should occur in late adolescence. While the need for specificity is necessary for competition and a required element of developing sports expertise (e.g., Little & Williams, 2005), it neglects any ongoing maintenance of the foundational movements upon which more specialised training is built (Hulteen et al., 2018; Lloyd et al., 2016). Nor does solely focussing on specific practice promote the continued development of general skills through greater movement diversification, a point related to the potential of GMA to support the reduction in injury risk. As a reaction to deliberate practice, the concept of deliberate play was introduced by Côté (1999), which is defined as encapsulating the foundational development of physical abilities, where involvement is intrinsically motivating and is enjoyable. Deliberate play is usually aligned to children in an early developmental stage, often referred to as a sampling stage, and could be aligned to the concept of GMA. Namely, diversification of movement development to underpin and support the evolution of higher-order movement skills. Interestingly, the difference between deliberate play and the promotion of GMA may merely be centred on when they are employed. In this thesis, I have considered the continued focus on promoting GMA as being lifelong rather than a specific period in a developmental process.

Indeed, there are specific examples where research has extended FMS training into adolescents, rather than only in childhood, and concluded that this is a reasonable way of promoting lifelong involvement in physical activity with positive health outcomes (Hulteen et al., 2018; Jaakkola & Washington, 2013).

Investigating the importance of GMA required an assessment tool which would measure both the individual's competency and would allow comparisons to norm data. Therefore, existing assessments were reviewed, though consideration of the historical context already covered in this thesis should be noted (see Section 2.2).

3.1.2 GMA assessment.

Historically, the assessment of GMA, as the perception of generic attributes which underpinned skilled movement, was used in identifying talented athletes for sports performance (Fleishman, 1958, 1964). This type of assessment, testing of some physical elements, remains popular, both in sports performance (e.g., Giles, 2007) and assessment of physical literacy (e.g., Canadian Assessment of Physical Literacy, Francis et al., 2016). As a consequence, this has led to the increased availability of numerous assessment tools, such as the Western Motor Ability Test (Campbell & Tucker, 1967), the Bruininks-Oseretsky Test of Motor Proficiency, second edition (Bruininks & Bruininks, 2005), the Test of Gross Motor Development (Ulrich, 2000), and the McCarron Assessment of Neuromuscular Development (McCarron, 1982). Although these tools do not explicitly describe the assessment of GMA, the assumption remains that this underlying ability exists (Ibrahim et al., 2011). Generally, motor assessment tools continue to derive a single composite score or group scores to represent motor capacity (Hands et al., 2018). While historically measures of general agility were traditionally based upon general motor skills and abilities. For example, Campbell and Tucker (1967) collected several GMA tests to assess performers; several of which remained in popular use (e.g., the Western Motor Ability Test). In contrast, contemporary practice is to employ more sophisticated tests which assess specific patterns of movement closely linked to sporting techniques; these have been developed and evaluated as part of integrated strength and conditioning programmes (Nimphius et al., 2018; Paul et al., 2016). Consequently, practitioners find themselves without a sense of how broad a spectrum of general movement skills are required on which to build more specific, technical patterns, or indeed how much transfer there is between the two; which is not helped by numerous pieces of conflicting research on this matter (Baker et al., 2003; Barnett, Ross, Schmidt, & Todd, 1973). Reflecting this apparent gap in knowledge and application concerning the use of general motor development, there are examples of experts offering very broad development packages of FMS, developing movement literacy (e.g., ESP, 2010), as well as those who have developed specific operationalised methods (e.g., Pearson & SAQ international, 2001). The almost parallel application of these philosophical, and most likely functionally, orthogonal approaches suggest a need for the assessment and quantification of both approaches. More specifically, how assessments that incorporate both these approaches would relate to performers who are still developing, both novice and youth athletes.

A further review of tests that have claimed to measure motor co-ordination reveals a vast array of protocols (Planinsec & Pisot, 2006). Both qualitative and quantitative tests are used in a variety of settings including clinical, educational, developmental and sport related (Chaiken, Kyllonen, & Tirre, 2000). These tests also vary in the extent to which they fulfil reliability and validity requirements, and some have no formal assessments of these critical measures. The range of elements covered by these motor coordination test, includes individual elements of co-ordination (Raczek, Juras, & Waśkiewicz, 2001), reaction time, agility and physical abilities (Baumgartner & Zuidema, 1972; Fleishman, 1964; Kollias, Hatzitaki, Papaiakovou, & Giatsis, 2001). As motor ability tests have developed over time, they have provided the opportunity to examine theoretical frameworks of many fundamental coordination elements which underpin specific movement patterns and therefore, successful human performance. Table 3.1 provides a short overview of some typical assessment tools.

Of the tests in Table 3.1, the Western Motor Ability Test (WMAT, Campbell & Tucker, 1967) is the only assessment that has been applied to the *elite* end of the spectrum. Specifically, WMAT has been used for the recruitment of physical education students on their measures of physical competence. Alongside the simplicity and ease of administration of the WMAT, norm values are available. It is also suitable for both sexes and its ability to discriminate performance made the test an appropriate choice for the studies in this thesis. The intercorrelations values of the four items in the WMAT are all large (see Table 3.2), and the reliability measures in Table 3.3 demonstrate large test re-test values, concluding that WMAT is a robust field test purporting to evaluate GMA. As with all GMA assessments, represented by the variety and scope of tests available (see Section 2.2), the WMAT can be perceived as representing an entity of GMA through the sub-components it tests. The agility run, standing broad jump, alternate hand ball toss and seated ball throw expressing: speed, agility, coordination, as well as lower and upper body strength and power seemingly cover a commonly identified and wide range of physical attributes (see section 2.3.1) which when combined into a singular value can justifiably be said to general motor ability or abilities. However, it should also be noted that a definite measure of GMA does not exist and therefore caution in describing the WMAT as the decisive assessment of it should be noted; the assumption being it is a representative measure of GMA. This is particularly relevant in the participant groups employed in this thesis, where the physical qualities in the WMAT are pertinent to RL players. Further commentary on WMAT is consider later in this thesis (see section 4.4.4).

Further investigation into the validity of GMA assessment tools may reveal suitable but more bespoke performance measures, and it is my aim to focus on developing such assessments in future research projects. Staying with *current* GMA assessments, it is worthy of note that there is a focus in a significant number of tests to identify dysfunction or assess the lack of appropriate motor abilities rather better performance (cf. Goyakla Apache, 2005). Lubans et al. (2010), in a review of FMS and their assessment, suggested that most validated measures of physical competence are designed to identify dysfunction rather than competence. The only motor skill tests designed for children appear to focus on identification of dysfunction (i.e., mild motor impairment; Van Waelvelde, Peersman, Lenoir & Smits Engelsman, 2007).

Table 3.1.

Sample overview of motor ability tests

Test	Purpose	Tests Elements
Bruinlinks-Oseretsky Test of Motor Proficiency (2005)	Assesses the motor proficiency of individuals	Gross and fine motor coordination, muscle strength, balance, and visual motor control
Devereux Test of Extremity Coordination	Primarily for emotionally disabled or neurologically impaired children	Static balance, motor attention span, and sequential motor activity
Lincoln-Oseretsky Motor Development Scale (1954)	Designed to test the motor ability of children 6-14 years old	Motor tasks such as walking backwards and one-foot standing, finger dexterity, eye-hand coordination, and gross activity of the hands, arms, legs, and trunk
Miller Assessment for Pre-schoolers (1982)	Screening assessment	Gross motor function in young children
Western Motor Ability Test (in Campbell and Tucker, 1967)	Assesses GMA	Agility run, alternate handball toss, standing broad jump and over arm basketball throw
Test of Gross Motor Development (2000)	A norm-referenced measure of common gross motor skills	Locomotor (run, gallop, hop, leap, horizontal jump, slide) and object control (striking a stationary ball, stationary dribble, kick, catch, overhand throw, and underhand roll)

Table 3.2.

Adapted from Campbell and Tucker, intercorrelations of WMAT

Variable		Item 1	Item 2	Item 3	Item 4
Composite Standard Score		.723	.874	.742	.711
Item 1	Agility Run		.607	.505	.457
Item 2	Standing Broad Jump			.501	.514
Item 3	Alternate Hand Wall Toss				.529
Item 4	Sitting Basketball Throw				

Table 3.3.

Adapted from Campbell and Tucker, test re-test reliability coefficients for WMAT

WMAT Items	*r*
Agility Run	.94
Standing Broad Jump	.90
Alternate Hand Wall Toss	.95
Sitting Basketball Throw	.89

The purpose of these dysfunction-focused assessments is to categorise participants and aim to target their deficiencies, for example, "if deficits in gross motor development are not identified and remediated, the child may experience lifelong problems with motor skills" (Ulrich, 2000 p. 1). These assessments while excellent for designing remediation for the bottom 5% of the population offer no potential to evaluate or remediate the majority in their general motor skills development. Therefore, this may severely limit their effectiveness at assessing and differentiating performance in better skilled performers. In this regard Collins, Bailey, Ford, MacNamara, Toms, and Pearce (2012) have recommended further research into establishing norm values, through improved representative movement competence assessments as the foundation of an accountable curriculum for FMS.

3.1.3 Describing the potential role of GMA.

Despite the frequent use of tools in assessing underlying sports performance, the recognition of the original concept of GMA has diminished. However, there may be merit in reinterpreting GMA as being more aligned with the perception of generic agility. Accordingly, GMA can be perceived as having a number of potential roles in the AD process: (a) representation of generic motor ability that feeds sport specificity, (b) an indication of coachability (cf. Psychological Characteristics of Developing Excellence (PCDE), MacNamara & Collins, 2011), (c) guidance in evaluating potential talent (Bailey & Collins 2013). These three points are summarily discussed.

General to specific.

The need to develop and maintain generic agility as athletes develop sport-specific motor abilities should not be underestimated (Kluwe, Miyahara & Heveldt, 2012; Sagas, 2013; Wiersma, 2000). This *twin-track* approach to developing sports performance seems sensible; attending to the specific requirements of a sports skill while also maintaining and enhancing the foundations on which it is built. It should be noted that while I acknowledge that other conceptual domains have been highlighted as important in the agility construct, for example, cognitive and environmental (Scanlan et al., 2014; Young et al., 2015; Paul et al., 2016), it is the physical aspects that are the primary focus of this investigation.

Coachability.

An individual’s coachability can be summarised as their potential to undergo sustained training, and can learn, adapt and cope with new challenges. This coachability is seemingly a desirable quality (Favor, 2011). Recently, there has been a view that promoting coachability can have a skills focus. MacNamara and Collins (2010) suggest skills are taught, assessed, practised and transferred into a new situation, as an athlete moves through a programme, and this process allows the athlete to learn and adapt better. Psychological Characteristics of Developing Excellence offer a framework in which this approach can be operationalised. These characteristics can be summarised as mental skills, including imagery and goal setting and "the attitudes, behaviours, and characteristics needed to negotiate the challenges, stages, and transitions, that typify development." (MacNamara & Collins, 2011, p. 1274). It is in this skill-based approach, where the development of Psychological Characteristics of Developing Excellence are to be advanced that changes in GMA or generic agility training may have a complementary role in fostering the characteristics that gifted individuals need to fulfil their talent potential (Collins, MacNamara & McCarthy, 2016). *Have a go-ness* or a positive approach to challenges (Abbott, Collins, Sowerby, & Martindale, 2007) is suggestive of coachability, that is, those individuals who are prepared to take on a challenge and are prepared and can cope with failure thrive, these qualities have been *shown* to discriminate performance level (Collins, MacNamara, & McCarthy, 2016). This concept of *have-a-go-ness* is reflected in some of the characteristics selected for coaches' rating of performance in athletes.

Talent development

Collins & MacNamara (2018) refer to the *process* of talent development, developing natural ability through a pathway to help maximise talent, rather than the spotting of talented individuals. They refer to the inputs (interpersonal and environmental catalyst) and the output of the pathway to the expert performer, talent being the output. MacNamara & Collins (2011) also stated that the goal in the talent development process was to build the capacity for future performance. With this in mind, they noted that the characteristics to cope with all types of challenges should be a vital part of the pathway. This "recognises the importance of focusing on an individual's capacity to learn and develop, rather than concentrating on what they already know or how they are performing at a particular time" (MacNamara & Collins

p. 1273). Developing the foundations of movement or FMS in the talent development process has been recognised as necessary (see Section 2.3.1). For both participation and performance, the common and fundamental set of abilities supports the transition between the two (Collins & MacNamara, 2018). Collins et al. (2012) Participation-Performance-Excellence Continuum provides as an example of a model that allows for the fluid transitions between participation and performance across time. Once again, the relevance of the concept of GMA, to acknowledge the importance of creating these movement habits and qualities in children and youth is interesting and requires investigation. At this point, it is worth restating the relevance of the PL concept (see Section 2.4.2). PL enables engagement in PA, by removing the barrier of poor motor competence (Hands et al., 2018; Abbott et al., 2007).

3.1.4 The importance of physical attributes and coach ratings of performance in RL.

One way in which the relevance of GMA may be evaluated is through consideration of its association with sport or context-specific abilities, characteristics and qualities. Perceived technical playing ability and possessing appropriate physical attributes have both been shown to correlate with higher skilled performers, particularly in RL players (Gabbett, 2002; Gabbett et al., 2007; Gabbett et al., 2009; Gabbett et al., 2010). While better physical qualities, which are generally described as fitness measures, are often seen as causative of their technical advantage. Subsequently the importance of appropriate physiological development has dramatically influenced talent identification and AD (Gabbett et al., 2010). It is the importance of these physical attributes that are now considered and examined.

The importance of physical attributes in RL.

Research has established the importance of certain physiological factors in RL, and their ability to discriminate playing level (Gabbett, 2002; Gabbett & Seibold, 2013) and effect performance. Explicitly in youth RL players, Waldron, Worsfold, Twist, and Lamb (2014) stated that early development of particular physical qualities might support critical game-specific skills in competition. For example, moderate to large differences between starters and nonstarters in junior elite and sub-elite RL players were identified in acceleration, maximum velocity (sprint times), and estimated maximal aerobic power (multi-stage fitness test) (Gabbett et al., 2009). Gabbett & Seibold (2013) confirmed this, as they found lower body strength (3-repetition maximum squat), upper-body strength and endurance (3-repetition maximum bench press; 3-repetition maximum weighted chin-up), and prolonged high-intensity intermittent running ability (Yo-Yo intermittent recovery test, level 1) discriminated performance in more and less successful semi-professional RL player. Gabbett et al. (2011) found that more experienced professional RL players were significantly better at accelerating (10 m) and had more lower-body muscular power (vertical jump) than their semi-professional counterparts. They also possessed significantly greater lean body mass (7-sites skinfolds).

Speed (20 m forwards & 30 m backs), repeated sprint ability (three sets of 3 repeat efforts, 20 m forwards & 30 m backs) and body composition (8-sites skinfolds) in rugby union players were highlighted as essential qualities (Smart, Hopkins, Quarrie, & Gill, 2014). In elite youth RL players, Waldron et al. (2014) demonstrated significant relationships in various age groups for ball carrying (carries·min^{-1}), 10 m force (derived force) and predicated vertical power (calculated from countermovement jump), but not defensive tackling ability, as important physical qualities. With regards to upper body physical attributes, maximal strength, maximum power and strength-endurance were all associated with playing RL at an elite level (Baker & Newton, 2006). Finally, Gabbett et al. (2011) suggested that to improve specific rugby skills strength and conditioning coaches should concentrate on developing acceleration and lower-body muscular power, demonstrating the importance of specific physical attributes to better performance in RL.

To date, however, no study has examined the association between a coach's ratings of playing ability (i.e., sport-specific), RL specific physical attributes and GMA. whether better GMA discriminates those who have better perceived technical abilities as well as superior physical attributes. It is these perceived technical abilities that I review and consider in the following section.

Coach ratings of performance in RL.

In exploring the Prerequisites and Precursors of Athletic Talent, Issurin (2017) identified several practical measures useful in talent identification and development process, such as participants having high *learnability* and an underpinning of GMA. This quality may help them in the learning and development of new movement skills (see Chapter Five). Similarly, participants may have such traits as intrinsic motivation, persistence, dedication, determination, and creativity. These could be characterised as psychosocial skills, for example mental toughness, emotional stability, self-regulation, and competitiveness. Specifically, Issurin (2017) in interviewing several Olympic athletes from different sports identified common psychological attributes referring to high levels of self-motivation, persistence, competitiveness, dedication, mental toughness, and emotional stability. Some of these qualities have been incorporated in the rating of perceived playing performance that coaches were asked to evaluate in this study.

To highlight the importance of technical abilities, which are supported by these psychosocial skills, Gabbett et al. (2011) inferred that tackling is perhaps the most crucial skill in RL. Defence structures are built on this skill in RL, which influences game outcomes. Research has also shown a significant negative relationship between tackling technique and the number of tackles missed as well as a significant positive relationship between tackling technique and the proportion of dominant tackles, confirming the influence of tackling in RL (Gabbett & Ryan, 2009). Wheeler, Wiseman, and Lyons (2011) found that ball carriers who offload in attacking RL play demonstrate a vital skill, which should be trained.

Describing the usefulness and discriminatory value of subjective evaluation of technical skills by coaches, Gabbett et al. (2007) stated that, although physiological or anthropometric information did not discriminate better or worse junior volleyball players, subjective coach assessments did. Therefore, these coach evaluations can be valuable in identifying vital skills in individual performers, and they also highlight the importance of these skilled techniques and characteristics.

To summarise, the lack of research acknowledging the existence and role of GMA in contemporary AD programmes is noticeable. This gap highlights the appropriateness of this investigation examining the association between GMA, vital physical components, and valued technical attitudes and personal characteristics of sport specific games play. This recognition is a valuable and novel addition to the scientific literature in AD

3.1.5 Aim of the study.

Reflecting the points above, this study aimed to investigate whether there was a link between an individual's GMA, physical attributes and coaches' ratings of playing ability. Specifically, I hypothesised that (a) there would be significant associations between WMAT and performance on physical tests (b) significant associations between WMAT and coaches' ratings of playing abilities, specifically a significant association between WMAT and an overall coaches' ratings of playing ability, (c) and there would significant associations between all physical tests and coaches' ratings of playing abilities.

3.2 Method

3.2.1. Participants.

The sample consisted of 33 junior RL players (mean ± SD; age: 16 ± 1 years; body mass: 79 ± 14 kg; height: 174 ± 6 cm) from a professional club. Participants were deemed suitable to take part in the study if they met all of the following criteria: (a) being free of significant injury for a period of three months prior to the commencement of the study, (b) physically active through engaging in a minimum of 150 mins of high intensity activity over a week, (c) familiar with the type movements involved in the study, and (d) ongoing membership of a Rugby Football league (RFL) academy for at least the preceding 12 months. Before testing, each participant was required to attend one familiarisation session in a sports performance area, where the testing protocols were explained and rehearsed. The participants read the description of the aim and objectives, risks, and necessary procedures of the study and a Physical Activity Readiness Questionnaire was completed. Ethical approval was provided by the Faculty of Health and Life Sciences' ethics committee at York St John University and also by Business, Arts, Humanities and Social Science ethics committee at University of Central Lancashire. Written informed consent was obtained from both participants and their parents or guardians.

3.2.2. Instrumentation.

CRoP questionnaire.

This research design was a cross-sectional comparative study where participants undertook a series of physical tests, including the WMAT (Campbell & Tucker, 1967), and tests for the general fitness constructs of strength, speed, acceleration, aerobic endurance and anaerobic endurance. Athletes were also assessed on a CRoP questionnaire.

The CRoP questionnaire provided 10-point Likert ratings on ten sport-specific game related characteristics and attributes and is detailed in Appendix A. This questionnaire was developed through a three-stage process. Firstly, items were generated against the stated aims of the investigation, using my experience and expertise in talent development of rugby players, in the last 20 years. This generation also drew on published material highlighting the needs for developing players in Rugby (Collins et al., 2016a, 2016b; Gabbett, 2002; Gabbett et al, 2009, Golby, Sheard & Lavallee, 2003) which provided a research-informed breakdown of the various characteristics and attributes targeted as a part of the academy process. This process produced 10 items which represented an extensive range of playing attributes (competence in rugby techniques, ability to apply technical ability in game-specific skilled performance, tactical awareness, physical abilities and qualities that support performance), alongside several playing characteristics (psychological qualities, sociological qualities, and intelligence) which are important in RL. Accordingly, the coaches were asked to rate players on items which held a clear context to their role (i.e., evaluating playing performance). For example, technical competence should not be interpreted as skill, nor should physical attributes be rated as technical competence (Phillips, Davids, Renshaw, & Portus, 2010). This was to ensure the distinction of items that were evaluated. The second stage involved the presentation of the questionnaire to an independent panel of four academy coaches, who were asked to comment on the usefulness and appropriateness of the constructs used. No changes resulted. Finally, the CRoP questionnaire was piloted with coaches on five academy players of the same age and stage as the target sample. After completion, cognitive interviewing was used to test for commonality and clarity of understanding (Willis, 2005). Once again, no changes were made with all pilot participants reporting an easy and common understanding of the constructs used. Each coach rated all participants on a Likert scale for all ten questions, and an overall coaches' rating was calculated.

Physical test.

The physical tests included: WMAT, maximum (max) wide chins, max dips, 10 repetition maximum (RM) back squats, 10 m sprint, 30 m sprint, the Triple-120 m shuttle test (T120; Holloway, Meir, Brooks, & Phillips, 2008) and a 5min run. The WMAT consists of four test components, the protocols are detailed in Appendix B.

The physical tests consisted of: (a) maximum chins, whereby participants completed their maximum number without stopping. One full chin constituted full arm extension, moving to the chin at or above bar height using an overhand grip, no extraneous use of the torso or lower limbs was allowed; (b) maximum dips, participants completed their maximum number without stopping. One full dip constituted full arm extension to elbow joint at a right angle or more acute (at least shoulder in line with elbow), hands were placed slightly wider than shoulder width, no extraneous use of the torso or lower limbs was allowed; (c) 10 RM back squats, an appropriate back squat technique was employed, the squat commenced from a fully extended position until the hips were at least the same height as the knee joint, defined as a parallel squat. The maximum weight lifted for 10 repetitions while maintaining correct technique and without pausing was recorded; (d) T120, participants performed three blocks of 120 m running separated by two periods of rest of 60 s (Holloway et al., 2008). Each work period consists of twelve 10 m sprints with a turn at each end. Specifically, on the 3rd, 7th and 11th interval the turn incorporated a simulated tackle. The simulated tackle consisted of a supine contact with the ground on the chest, rolling to one side onto their back, back to chest, rolling to the other side onto their back and finally onto the chest before rising off the ground. The total time for the three work periods was recorded; (e) 5 min run, the participants ran continuously for five min on a 400 m track, graduated in 20 m intervals. The test started and stopped on an audio signal, on the stop signal participants moved to the closet 20 m interval where their total distance was recorded. Participants were alerted with regular time checks, every minute of the test; (f) 10 m and 30 m sprints, using a two-point start, participants sprinted for 30 m down a straight track, total time was recorded using an electronic timing system (Smartspeed, Brisbane, Australia), and a split time at 10 m was noted. Once the participant was on their marks, they started under their own volition.

3.2.3 Protocol.

Each participant completed the series of physical tests, over a seven-day period, thus ensuring adequate rest between testing sessions. All testing took place on an outdoor 3G surface, with participants wearing boots, except for the alternate handball toss, which took place indoors. Each testing session began with a standardised 10 min dynamic warm-up, including running, bounding and dynamic stretching, followed by the respective experimental protocol. Order of completion was balanced across participants in a quasi-random format. Testing was carried out at the beginning of pre-season and under similar environmental conditions. All techniques were standardised as directed by an accredited strength and conditioning coach (United Kingdom Strength and Conditioning Association). The CRoP questionnaire was completed during this testing period; however, coaches were blind to the players' performance on the physical tests.

3.2.4 Data analysis.

Statistical analyses were performed with SPSS Version 24 (IBM Corporation, Armonk, NY, USA). Individual WMAT test component scores were converted into sigma scores, using norm values (adapted from Yuhasz in Campbell & Tucker, 1967) and a mean representative value was calculated for each participant. Sigma scores were derived for each participant, from norm value tables, for individual tests scores. WMAT norms for Canadian boys aged 16 years (adapted from Yuhasz in Campbell & Tucker,

1967) were used for this cohort of participants. The mean of four Sigma scores was calculated to represent an overall WMAT score. A mean of an individual's coaches' rating on all questionnaire items, measured on a Likert scale (1-10), was calculated to represent the coaches' overall rating variable. Preliminary analyses for normality (Kolmogorov-Smirnov) and homoscedasticity were performed. Pearson's correlation coefficients were established between factors, using a two tailed test. The *r* value was interpreted according to the values suggested by Cohen (1992) where 0.1 = small, 0.3 = moderate and 0.5 ≥ large when using a correlation coefficient. Statistical significance of 95% was used ($p < .05$).

3.3 Results

3.3.1 Preliminary results.

Ten RM Squat data was found to be slightly positively skewed (z = 0.47) so was log-transformed to achieve normality before any further analysis; all other data were normally distributed and homoscedastic.

3.3.2 Main results

GMA, as measured by the WMAT, was significantly correlated to performance in several physical attributes (see Table 3.4); upper body muscular strength, whole body acceleration, and speed as well as anaerobic endurance. Specifically, T120 time (r = -.49, < .01), 10 m sprint time (r = -.59, < .01) and 30 m sprint time (r = -.58, < .01) were significantly negatively correlated to WMAT. Whilst, max chins were positively related to WMAT (r = .38, < .05). The variance of individual physical qualities shared with WMAT were 24% (T120), 35% (10 m sprint), 34% (30 m sprint) and 14% (max chins). Max dips, 10 RM squats, and 5 min run distance had small and moderate effect sizes with WMAT, respectively, though none were significant correlations.

Examining the CRoP (see Table 3.4), the WMAT was significantly related to higher ratings of RL game-related attributes and characteristics. The WMAT significantly correlated with the overall coaches' rating (*r* = .35, < .05), being a moderate ES. Individual items, including: technical 1 (*r* = .54, < .01), playing ability (*r* = .40, < .05), practical awareness (*r* = .36, < .05), physical competence 2 (*r* = .46, < .01) and intelligence (*r* = .39, < .05) were all positively related to WMAT. Indicating that WMAT was significantly related to technical competence (e.g., ball handling technique), tactical awareness, qualities of alertness and focus, athleticism and intelligence (e.g., learning the game). Technical Competence 1, mental toughness, physical competence 1, teamwork had a moderate ES, although they were not significantly correlated with WMAT; as was courage with a small ES. The variance explained by each dependent variable on WMAT were 29% (Technical competence 1), 16%, (playing ability), 13% (practical awareness), 21% (physical competence 2), 15% (intelligence). Overall CRoP explained 12% of the variance in WMAT.

Table 3.5 presents the association between the measured physical attributes and the CRoP items. All but 10 m sprints and 10 RM squatting have some level of significant association with CRoP items. It would seem appropriate that coaches rate the importance of several playing attributes and characteristics with the physicality of individual performers alongside their GMA.

Table 3.4.

Pearson's correlation coefficients (*r*) for physical fitness scores and CRoP compared with WMAT; and descriptive statistics

Variables	**M (SD)**	**95% CI**	**WMAT**[a]
T120 (s)	125.06 (6.47)	122.77, 127.35	-.49**
10 m Sprint (s)	1.74 (0.09)	1.71, 1.76	-.59**
30 m Sprint (s)	4.36 (0.21)	4.29, 4.44	-.58**
Max chins (count)	9.48 (6.41)	7.21, 11.76	.38*
Max Dips (count)	14.36 (6.37)	12.11, 16.62	.19
10 RM Squat (log)	1.92 (.08)	1.90, 1.93	.04
5-min Run (m)	1207.88 (80.11)	1179.47, 1236.28	.33
Overall Coaches' Rating (mean of all attributes)	6.12 (1.20)	5.70, 6.55	.35*
Technical Competence 1 (ball handling, kicking)	5.87 (1.31)	5.41, 6.34	.54**
Technical Competence 2 (tackling)	5.53 (1.17)	5.12, 5.94	.21
Playing Ability (tactical awareness, support play, reading the game environment)	5.90 (1.41)	5.40, 6.40	.40*
Mental Toughness, (spirit, mental robustness)	6.02 (1.27)	5.57, 6.48	.20
Practical Awareness (alertness, focus)	6.27 (1.42)	5.77, 6.77	.36*
Physical Competence 1 (physical robustness, protection from injury)	6.21 (1.33)	5.74, .68	.11
Physical Competence 2 (General co-ordination, natural ability, athletic prowess)	6.58 (1.40)	6.08 7.07	.46**
Teamwork (social ability, communication, interactivity)	6.12 (1.19)	5.70, 6.55	.28
Intellect (ability to learn new skills, cognitive skills, decision making)	6.35 (1.22)	5.9, 6.41	.39*
Courage (heart of a lion, commitment to task)	6.39 (1.39)	5.90, 6.88	.10

Note. M = mean, SD = standard deviation, CI = confidence interval
[a] N = 33
* $p < .05$ (2-tailed). ** $p < .01$ (2-tailed)

Table 3.5.

Pearson's correlation coefficients (*r*) for CRoP and physical fitness scores

Variables	**Overall[a]**	**Technical Ability 1[a]**	**Technical Ability 2[a]**	**Playing Ability[a]**	**Mental Toughness[a]**	**Awareness[a]**	**Physical Ability 1[a]**	**Physical Ability 2[a]**	**Team Work[a]**	**Intellect[a]**	**Courage[a]**
T120 (s)	-.56**	-.61**	.39*	-.60**	.49**	.61**	.39*	.54**	.57**	.54**	.37*
10 m (s)	-.18	-.33	-.04	-.28	-.03	-.23	-.01	-.33	-.12	-.25	-.09
30 m (s)	-.41*	-.44*	-.36*	-.42*	-.27	-.39*	-.32	-.52**	-.34	-.39*	-.23
Max Chins (count)	.48**	.59**	.23	.45**	.47**	.51**	.37*	.38*	.36*	.54**	.44*
Max Dips (count)	.48**	.47**	.33	.37*	.55**	.40*	.45**	.31	.44*	.46**	.54**
10 RM Squat (log)	.17	.09	028	.12	.11	.19	.26	.18	.09	.15	.07
5-min Run (m)	.50**	.48**	.34	.38*	.55**	.48**	.5**	.49**	.35*	.46**	.56**

a N=33

* $p < .05$ (2-tailed). ** $p < .01$ (2-tailed)

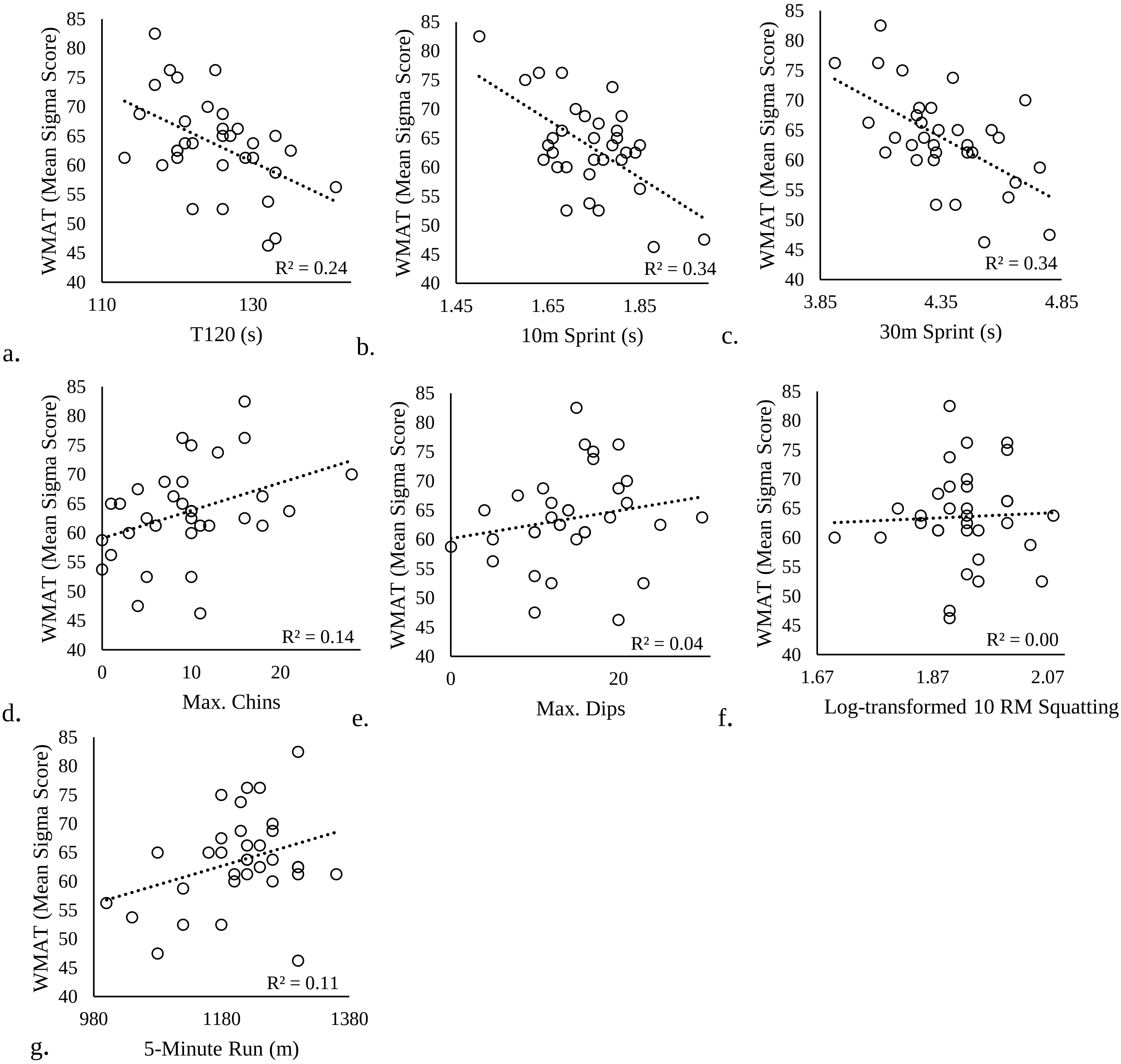

Figure 3.1. Variance (R^2) WMAT shares with physical attributes

3.4 Discussion

The study aimed to compare GMA, as measured by WMAT, with physical attributes and CRoP. These results highlight significant associations between GMA and the physicality which is important in RL performance, as well as significant positive associations between GMA and ratings of playing ability as identified by skills coaches. The use of a GMA test, albeit a notably historical and straightforward approach, appears to discriminate those performers that a coach would identify as having good playing attributes and characteristics, as well as positively relating to those physical attributes that have previously been identified as being of high value in RL (Comfort, Graham-Smith, Matthews, & Bamber, 2011; Gabbett et al., 2009; Gabbett, 2002; Kirkpatrick & Comfort, 2013). The results also highlight the varied associations that measures of physicality directly have with ratings of playing ability in RL players (Gabbett et al., 2011). Therefore, all hypotheses can, to some extent, be accepted; partially accepting the first hypotheses that there are significant associations between WMAT and some physical performance measures. The second hypothesis, that WMAT significantly relates to CRoP, can also be partially accepted, specifically that there is a significant association between WMAT and an overall measure of CRoP. While the third hypothesis, identifying significant associations between various physical tests and element of the CRoP, can be partially accepted.

3.4.1 Physical attributes and WMAT.

The findings demonstrate (see Table 3.5) that participants who are faster at completing a test for anaerobic endurance (T120, r = -.49, < .01), and those who are faster over 10 m (r = -.59, < .01) and 30 m (r = -.58, < .01) sprints are the performers who have higher WMAT scores. Previous studies have found similar results in high-level rugby union players and junior soccer players, where repeated sprint ability and speed were identified as important physical attributes (Hammami et al., 2017; Smart et al., 2014) Another positive association in upper body strength and WMAT was identified, where a high number of maximum chins significantly relates to a better WMAT score (r = .38, < .05); this is a moderate ES. Upper body strength and endurance have previously been shown to discriminate success in semi-professional RL players (Gabbett & Seibold, 2013). Although the variance in WMAT performance shared with these significant physical qualities (T120, 24%; 10 m sprint, 35%; 30 m sprint, 34%; max chins 14%) was less than 50%, this data does suggest that WMAT may play a role in defining performance in important RL attributes (see Figure 3.1). While individually the shared variance is low in these variables, and therefore may show a weaker ability to solely predict outcomes on WMAT. It may be that it is the collective influence which is the defining factor in recognising the importance of GMA (Hands et al., 2018). This matter is discussed in further detail in Chapter Four (see Section 4.4.2).

It should be noted that not all the physical assessments had significant correlations with WMAT (see Table 3.4), 10 RM squatting (log transformed), max dips and 5-min run distance had, at best, moderate ES. The shared variance WMAT has with log-transformed 10 RM squatting (0%), max dips (4%) and 5min run (11%) were very small, this suggests that WMAT performance had little impact on these qualities. It remains, however, unclear why these types of physical attributes did not associate with GMA performance in this sample. Previously, research has found that aerobic capacity, upper and lower body endurance and strength can discriminate RL performance (Gabbett et al., 2009; Gabbett & Seibold, 2013). Whether this reflects the specific development and conditioning status of this particular sample is uncertain.

Therefore, being able to directly link GMA level with physical attributes that facilitate a specific sporting performance (RL) provides further support for importance and role of GMA. This confirmed link between physical components and GMA may well strengthen the notion that generic agility (Liefeith, Kiely, Collins, & Richards, 2018), a manifestation of GMA, does relate to physical attributes that are specifically important in RL.

3.4.2 CRoP and WMAT.

The expression of the qualities and skills that appear on the playing pitch, which coaches' rate and value alongside an assessment of GMA, are discussed here. The CRoP exhibited a number of significant associations with the WMAT, and these ratings can be broken down into several distinct areas: technical competencies (technical 1, r = .54, < .01), playing skills and tactics (playing ability, r = .40, < .05; practical awareness, r = .36, < .05), physical elements (physical competence 2, r = .46, < .01), psychosocial characteristics and cognitive attributes (intelligence, r = .39, < .05). There seems to be a positive link between an individual's GMA and their potential playing ability. Although not established as causal, assessing GMA may support the selection of young athletes that have a propensity of valuable qualities and characteristics that a talent development programme or a coach would be seeking. Specifically, Wheeler et al. (2011) research demonstrated similar findings to this study concerning coaches' responses and playing ability. For example, technical competencies (cf. technical 1 of the CRoP questionnaire) as defined by ball handling ability, is important in attacking skill in RL (Hendricks, Lambert, Masimla, & Durandt, 2015). Consequently, the large positive association WMAT has with technical competencies is suggestive that these specific ball handling skills are represented by higher GMA.

To further support this point, the specific hypothesis stating that there would be a significant association between WMAT and an overall measure of CRoP was accepted (r = .35, < .05). This overall rating, comprising technical competencies, playing skills and tactics, physical elements and psychosocial characteristics and cognitive attributes, and its moderate positive association with WMAT, establishes the apparent association with essential playing attributes and GMA.

As part of the CRoP questionnaire, coaches were able to make a clear distinction between technical competency of rugby specific techniques, and the interaction of several tactical, strategic and spatial skills, to produce a rating of playing ability. Clarifying this distinction is just one example of how the coaches' rating of the participants' performance, provided a holistic and straightforward interpretation of each individual's playing potential. It is this significant association with GMA that provides a compelling argument for its importance as a tool to guide the selection of gifted individuals (Collins & MacNamara, 2018). "Talent identification programs in sport require the assessment of individual movement skills through several stages. Firstly, one screens individual organic and motor attributes to assess motor ability. Then follows a phase of sport-specific skills testing and talent development" (Ibrahim, 2009, p. 1). This statement encapsulates the continued importance of movement skills throughout the development process, that then leads to sports specificity. As previously discussed, Ibrahim's approach may have issues related to a more linear process, and the more progressive interpretation of the twin-track may be more appropriate, whereby, the simultaneous development of generic and specific movement skills occurs. Nonetheless, GMA assessments can be seen to be supporting both the identification of potential, but also representing the status of the building blocks on which the complex skills which are essential sport-specificity, are founded. It is these FMS, which are encapsulated by GMA that Giblin et al. (2014) suggested underpins the whole range of physical activities, from typical daily movement tasks to high-level sport specific tasks. Some of the items in the CRoP questionnaire were not significantly related to specific physical attributes (10 m sprint & log-transformed 1 RM squats), as to why these specific items did not correlate to the same extent is inconclusive and requires further investigation.

3.4.3 Physical tests and CRoP

As an overview to these results, all physical fitness scores had at least one moderate interaction with one of the items of the CRoP, while there were specific physical fitness scores (T120, max. chins and 5-min run) that had multiple large associations with various technical playing abilities (see Table 3.5). Previous research confirms the findings of this study, that is, high levels of physical attributes contribute to effective playing ability in players, as reported by expert coaches (Gabbett, 2002; Gabbett et al., 2007; Gabbett et al., 2009, Gabbett et al., 2010). These findings demonstrate the interactive association between physical attributes and the coaches' rating of technical competencies, playing skills and tactics, physical elements and psychosocial characteristics and cognitive attributes, which are important in RL performance. Though not a causal association, in a more exploratory manner, there seemingly is a link between good GMA, appropriate physical attribute and valued games playing characteristics.

3.4.4 Deliberate preparation, GMA and early specialisation.

It has been shown that better development and attainment of FMS in early years, positively relate to outcomes in physical, behavioural, psychological and academic, that are lifelong (Giblin et al., 2014; Lubans et al., 2010). Indeed, these researchers state better motor coordination, above and beyond FMS, continue to impact the physical, behavioural, psychological and academic factors. To this end Giblin et al. have further developed the concept of deliberate practice and deliberate play and suggested the concept of deliberate preparation. They describe this concept as:

> "Deliberate preparation proposes that structured physical skill development could provide a situated learning environment for students to acquire the behavioral and psychological skills that improve physical ability and one's perception of ability and increase

appreciation of the importance of leading a physically active life" (Giblin et al., 2014, p. 391)

It is proposed that deliberate preparation helps integrate multi-dimensional aspects of improving physical ability in either a participation or performance environment. The finding in this study resonate with the concept of deliberate practice, whereby there are significant integrated associations between the examined variables. This interactive association between GMA, physicality, and CRoP also relates to the taxonomy presented by Burton and Rodgerson (2001), i.e., skill sets in a more specific movement are supported and underpinned by a GMA. Specifically, that the abstract composite score of the WMAT represents movement skill foundations or FMS, which in the findings of this study have been shown to correlate to physical performances and coaches' rating of playing attributes. These are what Burton and Rodgerson might describe as movement skill or movement skill sets. Interestingly, these qualities that are shown to relate to GMA may also represent the capacity of an individual to learn, control, and perform movement skill (Hands et al., 2018). This *coachability* or adaptability may be enhanced through an ability to efficiently negotiate a diversity of movement challenges, underpinned by a range of well-developed sub-capacities, and manifest itself in motor learning and skill transfer.

3.4.1 Chapter summary.

The results of this study have established a role GMA can play in AD, by its significant association with specific attributes and qualities generally required in team sports; therefore, contributing to the knowledge base in acknowledging the role of GMA and advancing the evidence base for practitioners involved in AD. The specific physical attributes of upper body muscular strength, whole body acceleration, speed and anaerobic endurance, as well as overall CRoP, are significantly related to WMAT. Indicating that possessing better GMA aligns with the attributes which underpin the specialised skills and qualities required for RL. Accordingly, these findings support the existence of GMA, and its potential role and importance in developing RL players. This evidence, that GMA relates to specific performance attribute important in RL, highlights the novel contributions these findings add to scientific knowledge in the AD. Though not a causal relationship, this does indicate that the generic qualities represented by GMA may discriminate those better-skilled performers in real playing scenarios. Limitations in the data set do raise analytical issues that cannot be ignored, for example, low participant numbers; this may mean that the discussion points are less generalisable. Similarly, the consequence of using simple correlation on such a small sample size also presents potential issues of statistical power. It should be acknowledged that the use of multiple correlations repeatedly on the same data set may have an impact on the interpretation of the correlation coefficients. The possibility of a type I error when using the same data set to analyse the association in a number of variables, greater chance of identifying a stronger correlation in the sample due to this type of error. Contribution to this type of error may centre around the sample size and the extent of variables being correlated. Notwithstanding these limitations, this study highlights important and interesting findings that may influence the use of GMA in AD programmes. Speculatively, this may relate to those practitioners working with established elite athletes, as opposed to solely children and youths. Therefore monitoring, developing and maintaining a base of GMA, operationalised through generic agility training, may help to discriminate performers in team sport, and underpin specific physical attributes and technical playing qualities and characteristics which defines and creates expertise.

Chapter Four

How Might it Work? Exploring Mechanisms Underpinning GMA

4.1 Introduction

In chapter Three the associations between GMA, physical attributes, and technical abilities were evaluated and discussed. This chapter examines an individual's GMA and how it is related to context-specific movement patterns; specifically, the association GMA has with general and specific CoD performances. These CoD tasks represent general and specific movements previously acknowledged as being important in sports performance (Nimphius et al., 2018), and explicitly in RL (Paul et al., 2016). Therefore, the primary aim is to describe how these CoD movements situated within a broader interpretation of agility, generic and specific agility (Liefeith et al., 2018), relate to GMA. A secondary aim explores the mechanical factors which underpin the CoD performances, examining the link between specific CoD patterns and the kinematic solutions participants produce to optimise their performances.

In researching agile behaviours and abilities, there has been a recent focus on testing and training more sport-specific agility movements, especially in applied practice (Čoh et al., 2018; Davies, Young, Farrow, & Bahnert, 2013). This focus may have compounded the issue of early sports specialisation (Mostafavifar et al., 2013). To the detriment of maintaining a sense of broader motor abilities. In this regard, Green, Blake, and Caulfield, (2011a) acknowledged that agility is a discriminating factor of performance specifically when compared with other physical attributes and anthropometric measurements (Farrow, Young, & Bruce, 2005; Gabbett & Benton, 2009; Sheppard, Young, Doyle, Sheppard, & Newton, 2006). This discriminatory ability seemingly includes tests that have a reactive element as well as those using solely preplanned agility movements.

The evidence presented in this chapter supports the use of GMA as a predictor of, both, generalised and specific agility. It highlights its importance in the broader development and progression of movement skills, or motor competence, for context-specific sporting success (Barnett et al., 2016). The findings support the conceptual and practical use of GMA in, (a) assessment for the identification of athletic giftedness, (b) as a training modality and, (c) in providing a foundation of FMS for skill development and transfer. The contribution of this evidence to scientific knowledge is novel, the identification of a GMA which connects both generic and sport-specific CoD is contemporary and unique and has the potential to challenge current AD practice.

4.1.1 Issues related to specificity in training practice.

In Chapters Two and Three some issues related to the early specialisation within AD programmes were discussed, and the manner in which assessing and developing GMA to counteract this narrowing of movement specialisation has been proposed. Specificity in developing motor competence and its impact on training practices, has been an influential factor on early specialisation. This specificity of training practice, particularly in applied strength and conditioning, has become normal; supported by a recent focus in literature (Chaalali et al., 2016; Ericsson, Roring, & Nandagopal, 2007; Baker, Wilson, & Carlyon, 1994; Ford et al., 2009; Shea & Kohl, 1990). In the context of GMA, specificity of training has continued to side-line the role of developing more generic movement skills. A study by Ellison et al. (2017) challenged the existence of general motor abilities, such as EHC, they stated that their "study has provided further evidence against EHC as a general ability" (p. 6). They concluded that practitioners should pursue improvements in performance through more sport specific training and tests. Conceptually, the importance of specific practice is evident, to gain the desired outcome from, learning, training etc. targeted and specific must be undertaken (e.g., Meir, Holding, & Hetherington, 2014); the role and necessity of this specificity are no being questioned here. Further to this, in contemporary strength and conditioning practice, the continued shift to specific practice to support competition has been noticeable, particularly in training for team sports. In this applied approach, there is seemingly a strong perceived link with the specificity of practice and developing authentic competition experience (Čoh et al., 2018). It is suggested that the closer to actual competition work in training represents the best developmental environment for transfer to competition and subsequent success (Baker et al., 2003; MacMahon, Helsen, Starkes, & Weston, 2007). Although this is a popular concept, speculatively, this is perhaps an area where an appropriate balance between developing specificity and maintaining general movement skills can be considered and further explored.

Marshall et al. (2014) described exercise specificity as important in programme design, stating that "coaches seek to provide training exercises that target specific factors" (p. 2845). For example, the context specificity of visual feedback was examined by Moradi et al. (2014), who concluded that participants, on a retention skill test, performed worst if the visual context differed from when the task was first learnt. In a test of sensory feedback further evidence for a specificity hypothesis was presented, through the manipulation of visual and auditory information (Coull, Tremblay, & Elliott, 2001).

As the evidence, regarding specificity, is equivocal, further investigation into the consequence of narrowing a movement repertoire is required. However, research does demonstrate that specificity in learning motor skills, and ensuing practice, is essential for developing higher levels of motor competence, there is also a philosophy that creating a broader base of motor competencies supports the development of expert performers (e.g., Lloyd & Oliver, 2012).

Consequently, despite the focus on sports specificity in training and general development being in vogue, the potential for the utilisation of more general movement development (e.g., Liefeith et al., 2018) has prompted a re-examination of the concept of GMA. This updating of the agility construct highlights the importance of general movement qualities, and the sub-capacities they are built on. (see Section 2.3.1). The existence of GMA, generic entities that underpin applications to and transfer between sport-specific performance, has been a recurring theme in academic and practitioner-focused literature (Burton & Miller, 1998; Campbell, & Tucker, 1967; Fleishman, 1964; Magill, 1993, 2001). Research has positively highlighted evidence for such a concept (Ibrahim et al., 2011), although it remains under scrutiny in some quarters (Ellison et al., 2017). GMA is said to underpin the development and, ultimately, attainment of movement skill sets in more specific challenges; for example, sport specific movements (Burton & Rodgerson, 2001; Stodden et al., 2008). In their review, Ibrahim et al. (2011) identified motor abilities as being potentially innate, stable or developed over time. Whereas (Hands et al., 2018), explains that GMA is inferred from tasks of movement skills and reinforced by FMS and that it cannot be directly assessed.

To clarify, the interpretation I use in this thesis suggests that GMA does not mean general motor abilities, but I refer to a GMA. Explicitly, it is a singularity which represents an expression of an individual's motor ability. Therefore, this underpins the development of more complex and sophisticated skilled performances. This explanation of GMA does allow and facilitate better performance higher up the hierarchy of skilled movements in a taxonomy of skill (see Section 2.2.2) and proposes that an individual can capitalise on their GMA in more context-specific environments as skills evolve. This proposal that GMA is a singularity, being interpreted as the sum of fundamental attributes, is the focus of this thesis. Basic functions and capacities which create and produce movement, are the entities which summarily manifest themselves as a GMA. The debate whether these individual functions can be summarised, into a global ability or need to be viewed as separate and specific, is ongoing. The corresponding solution to this discussion may be a matter of perspective.

4.1.2 Evaluating the importance of agility and CoD in sports performance.

CoD has been recognised as being important in sports performance, particularly in team-sports (Loturco, Nimphius, Kobal, & Bottino, 2018), though the debate surrounding the concepts of both agility and CoD is ongoing. As previously discussed, (see Section 2.3) the various definitions of agility in the literature suggest a lack of consensus as to what agility entails, this is alongside the broad context in which the term agility is used in both applied and research contexts. However, the relationship between a concept of agility and CoD ability has been widely studied (Brughelli, Cronin, Levin, & Chaouachi, 2008; Sheppard & Young, 2006; Young, 2006; Young & Farrow, 2013), with the distinction between the two remaining a contemporary and disputed issue. For example, Sasaki, Nagano, Kaneko, Sakurai, and Fukubayashi (2011) stated that CoD ability was a crucial factor in the development of elite level footballers and was the strongest predictor for identifying talent: CoD often being conceived as being a component of agility (Sayers, 2015). Although interpreting CoD ability also remains under scrutiny. For example, although there is a range of understanding, Loturco et al. (2018) concluded that there remains a lack of consensus in the assessment and development of CoD ability. The main point of the debate surrounding agility and CoD ability centres on the related issues of preplanned CoD (CoD_{pp}) ability and reactivity CoD (CoD_{r}) (Scanlan et al., 2014; Spasic et al., 2015). Current literature has described preplanned and reactive agility as being distinct qualities (Čoh et al., 2018; Little & Williams, 2005; Lockie, Jeffriess, McGann, Callaghan, & Schultz, 2014; Matlák et al., 2016; Spasic et al., 2015; Vescovi & Mcguigan, 2008). In *stop-and-go* reactive-agility protocols compared with CoD performance, Sekulic, Krolo, Spasic, Uljevic, & Peric (2014) identified a 10-20%

difference in PT. In contrast, there is evidence to suggest that although performance between the activities is mechanically different, the two movements are related (Gabbett, Kelly, & Sheppard, 2008; Henry, Dawson, Lay, & Young, 2011) and the underpinning physical qualities are similar (Nimphius, Mcguigan, & Newton, 2010). Regardless of this, CoD ability is recognised as a critical attribute in sport (Nimphius et al., 2018), particularly in games activities (Fiorilli et al., 2017)

To provide some context, in this thesis I refer to CoD_{pp} as meaning a single CoD in a predetermined direction incorporating a preceding and subsequent sprint; and CoD_r as the same for CoD_{pp} with a reactive element. This reactive element acknowledges the importance of the cognitive component in this action (Gabbett & Benton, 2009). This interpretation is similar to that of Nimphius et al. (2018) when defining CoD which can be applied to both preplanned and reactive conditions. However, they did restrict their definition of CoD to the actual *change* of direction event, rather than the whole CoD performance across time; including pre and post sprinting. In this chapter, the term CoD_r refers to what might be commonly referred to as agility (Sheppard & Young, 2006). This distinction is made to avoid any misinterpretation in the new definition of generic and specific agility offered in this thesis (see Chapter Two).

Evidence suggests that agility movement with a perceptual and decision-making aspect distinguishes different levels of performers (Young & Farrow, 2013). This interpretation has led to agility being more closely aligned with CoD movements than cognitive elements (DeWeese & Nimphius, 2016), whereas CoD without reference to any reactivity has been described as manoeuvrability (Nimphius et al., 2018). Although any CoD_{pp} does, by its definition, not involve any reactive cognitive elements, it is still, however, a skill that has been identified as necessary in open field environments (Jeffreys, 2011; Spiteri, Hart, & Nimphius, 2014; Young & Farrow, 2013). For example, in a predetermined attacking strategy immediately before engagement with a defensive line (Nimphius et al., 2018; Spasic et al., 2015). Common in RL, this running action can often be seen in dummy running or in attackers who are *hitting a hole* in a defensive line. Both these types of actions can be referred to as *running a line* and may involve some deception on the part of the attacker where they begin a run in one direction before dynamically altering their direction of the run to create uncertainty and space in a defence (Wheeler & Sayers, 2011). From a fundamental motor learning perspective, there is a general agreement that CoD_{pp}, is an essential prerequisite of the distinct CoD_r ability and its subsequent development. Evidence from a previous study concluded that the use of CoD as part of a multidirectional CoD training programme was significantly effective in developing sport-specific attributes, as measured by a range of performance tests, including tests of reactive agility (Chaouachi et al., 2014). Chapter Five examines whether generic agility training used in developing motor competence in younger performers or employed as a training modality in athletes developing their levels of strength and conditioning (Nimphius, Callaghan, Spiteri, & Lockie, 2016; Spiteri, Nimphius, et al., 2014; Suchomel, Nimphius, & Stone, 2016) influences CoD_{pp} and CoD_r performance.

CoD_{pp} can be relevant to more open field sports in specific situations (Dos'Santos, Thomas, Jones, & Comfort, 2017) and, therefore, this type of CoD movement should perhaps not be considered generic or non-sport specific and having little value in the preparation of field athletes. Spasic et al. (2015) suggested that CoD_{pp} is more associated with team games players, rather than activities such as tennis, where there are more stop-go direction changes. Despite previously presented evidence that there is little association or transfer between preplanned and reactive agility movements (e.g., Simonek, Horicka, & Hianik, 2016), Gabbett and Benton (2009) stated that reactive agility is distinct from preplanned movements, highlighting the perceptual and decision making elements as the defining factors. In contrast, Lockie, Schultz, Callaghan, Jeffriess, and Berry (2013) suggested that CoD_{pp} and CoD_r can be recognised as the same type of activity. The evidence, therefore, is inconclusive, although it is suggested in this study that commonality does exist, and speculatively that generic elements underpinning both groups of movements can be collectively identified and represented through a GMA.

The number of direction changes and duration of the CoD task has previously been shown to influence the physical qualities being measured (Nimphius et al., 2017), with multiple directions effecting the deceleration- acceleration relationship, therefore where the emphasis of the task lies. Whereas the stop-and-go CoD tasks (Sekulic et al., 2014) introduces other focuses on performance, for example, deceleration to a complete stop before re-acceleration. Duration of the task will influence where the adaptive impact lies with the mechanics of the direction change, the linear speed, or more crucially the metabolic demands (Nimphius et al., 2016). Nimphius et al. described how some CoD performances (e.g., Illinois agility test) might identify limits in metabolic conditioning rather than CoD ability. The focus in this study was the CoD action itself, within a non-stop running-based task. To reiterate, Spasic et al. (2015) suggested that this type of CoD movement is more associated with team games players rather than activities such as tennis, where a decelerate to a stop and accelerate action is more common. Therefore, in this investigation there was an emphasis on maintaining velocity, perhaps resulting in a more curvilinear running (Condello, Kernozek, Tessitore, & Foster, 2016; Nimphius et al., 2018), though the running pattern in the data collection was prescriptive in influencing an outside cutting CoD action. Accordingly, the CoD tasks used in this study had a single 45° cut, preceded and followed by linear running, similar to a previous procedure (Green et al., 2011a).

As a point of reference, it should be noted that the CoD deficit has been previously proposed to accurately evaluate CoD performance. Purported to assess actual CoD ability (Nimphius et al., 2016a), as opposed to the incorporation of linear sprinting speed within overall CoD PT. The CoD deficit calculates the difference in CoD PT and linear sprinting performance, Nimphius et al. suggested that this measure better isolates the CoD ability of a performer. However, for this study the broader understanding of CoD was used, that is, overall PT including sprinting, deceleration and acceleration, and the CoD event.

Henry et al. (2016) measured various aspects of strength; unilateral strength was found to have a low correlation with reactive agility (CoD_r), though they did identify skill, balance, and coordination as being essential motor components that would influence reactive performance. While this evidence exists, however, it does raise an issue in how collectively findings are interpreted, particularly when examining a more holistic effect; such as GMA.

Previous literature has identified that CoD_r has ecological validity (Paul et al., 2016), and it represents authentic game-specific movements. This aspect of testing has been discussed further with regards to the nature of the stimulus presented. A light stimulus has been described as less valid than a real presentation of a stimulus, i.e., a person (Henry et al., 2011; Nimphius et al., 2017; Young & Farrow, 2013). Oliver and Meyers (2009) discussed the merit of a light-based stimulus in a reactive agility test. In describing the similarity in this test and a preplanned agility test they suggested that there are common or shared physical elements that explain this association. However, the literature indicates that the difference in reactive and preplanned CoD comes into play when a sport-specific stimulus is used, requiring interpretation by the performer of more sports-specific cues. In this study, the stimulus was presented by a researcher. This authentic stimulus offered a context-specific stimulus which defines the reactive CoD task as being different from the preplanned task, and highly relatable to sports performance. The shared physical elements that Oliver and Meyers (2009) suggest underpinning general agility include acceleration, ability to change direction and ability to react to a stimulus, which is seemingly closely allied to my concept of generic agility.

4.1.3 Interpreting the new definition of agility.

Having already defined CoDpp and CoDr, I intended to use the term agility as described previously (e.g., Liefeith et al., 2018) and not, as frequently regarded, solely in the context of explicitly changing direction (see Section 2.5). This view has given rise to my interpretation of the *agility* construct, as such having both generic and specific components and it is this interpretation of agility that I turn to in exploring GMA and how it might work.

The role of generic agility in operationalising GMA.

My definition of *generic agility* is an ability to efficiently negotiate a sweeping diversity of movement challenges, underpinned by an extensive range of well-developed sub-capacities, and it is this quality that I speculate is closely aligned with GMA. Generic agility may, therefore, be perceived as a manifestation of GMA. It is, therefore, the investigation into the relationship between CoD_{pp} and GMA, as a representation of generic agility, that was one of the aims in this study. As the concept of generic agility (GMA) has been discussed (see Section 2.3, & 3.1), it may be appropriate to reiterate some of the potential benefits linked to it, that may relate to CoD performance:

- Fundamental movement skills reportedly underpin higher order skills (Burns et al., 2017; Vandorpe et al., 2012) and motor competence influences physical activity, with both participation and performance (Malina, 2009; Stodden et al., 2008)
- Physical attributes support the development of skill (Jaakkola & Washington, 2013; Serpell, Young, & Ford, 2011). PE incorporating deliberate preparation supports academic achievement and social development (Giblin, et al., 2014).

- Psychosocial characteristics such as cognate and problem-solving ability are essential in athlete development (Kushner et al., 2015; Wulf & Shea, 2002), while the adaptability to challenge, promotes positive behavioural change, in skill orientated tasks, such as games play (Kushner et al., 2015).

It is these various characteristic, abilities, and attributes that I propose can be holistically represented by generic agility, to varying degrees; although it is precisely the physical and cognitive elements which are particularly under scrutiny in this thesis. It should also be noted that in the commonly utilised models of AD (see Section 2.4), the concept of developing a range of FMS is well established. However, the development of these basic movement patterns in younger athletes is mechanically similar but conceptually dissimilar from the suggested proposal here. I recommend that generic agility be continually developed and maintained throughout an athlete's lifespan, not only in early years' development (see Figure 2.2). This twin-track approach is necessarily different from the more linear and chronologically related approach, to develop FMS, that current popular development models utilise.

Specific agility representing sport specificity.

Once more, referring to my interpretation of the agility construct, I define the *specific* aspect of agility as being characterised by an ability to accurately 'solve' the narrower sub-set of movement problems commonly posed within a sporting context. This *specific agility* is what is seemingly employed in more context-specific sporting performance, which is necessary for achievement and ultimately it defines outcomes. Earlier, in Section 4.1.1 there was a review and discussion of specificity and GMA; therefore, those points raised are pertinent when considering specific agility. The low intercorrelation relationships between more general CoD or motor competency has led researchers to accept that task specificity is essential (Giboin et al., 2015; Henry, 1958; Loockerman & Berger, 1972), leading to the notion that motor abilities are task specific and that there are many motor abilities which are unrelated (Yazdy, 1985). Hands et al. (2018) ably summarised this perspective “Thus, a newer view prevailed that individuals proficient in performing a wide range of movement skills possessed many different, specific abilities and that patterns of specific abilities involved in successful motor performances differed among different individuals” (p 214). Therefore CoD_r, in this study, can be interpreted as a manifestation and representation of specific agility. Zemková (2017) suggests that measuring agility of a more sport-specific nature is superior and more appropriate than tests that assess CoD. Extending this, Zemková proposed that these specific assessments should be specific to player level or player position. It appears that research predominantly focuses on reactive agility when assessing RL agility performance (Gabbett & Benton, 2008; Serpell et al., 2010), with the primary focus upon the cognitive aspects of CoD. An important point as previously highlighted is that high-level athletes have been shown to have a greater ability when deciding to react to an external stimulus (Farrow et al., 2005; Sheppard et al., 2006). Therefore the ability of these better performers to *read* a situation and anticipate opponents allows them to create more effective CoD movements in their responses (Jackson, Warren, & Abernethy, 2006; Wheeler & Sayers 2010).

4.1.4 Understanding the mechanics of CoD.

Research into the underpinning mechanisms or the mechanical factors that are used in agility movements, specifically COD performance, is an emerging area of study (cf: Fox, 2018; Nimphius et al., 2018). Mechanically focussing on the CoD event (CoD step) has been suggested to better define the CoD (Sayers, 2015), rather than evaluating overall PT. There is a significant amount of research that has focussed on understanding the mechanics of CoD, from a loading or injury mechanics perspective (Havens, & Sigward, 2015; McLean, Lipfert, & Van Den Bogert, 2004; McLean, Walker, & Van Den Bogert, 2005 Nimphius et al., 2017; Sanna, & O’Connor, 2008).

While the importance of agility is cited as key to athletic performance (Havens & Sigward, 2015; Dos'Santos et al., 2017) and a determinant of success, mechanical understanding is still developing. However, Spiteri, Cochrane, Hart, Haff, and Nimphius (2013) stated that "understanding the magnitude of forces and lower body kinematics that occur during a CoD task can provide information about the biomechanical demands required to improve performance" (p. 646). Despite this importance, however, examples of kinematic analysis for performance in the literature are less common. With respect to previous focus on more global kinematics and a lack of detailed mechanical analysis (Nimphius et al., 2018) consequently serves to rationalise the study presented in this chapter. Young, James, and Montgomery (2002) discussed stride mechanics, and body orientation with regards to CoD performance, while Inaba, Yoshioka, Iida, Hay, and Fukashiro (2013) examined the roles of hip abduction in sidestepping actions at various distances on force production and orientation. However, Loturco et al. (2018) have reiterated that CoD ability, the point at which the CoD action occurs, is a definite quality. CoD speed (CoDs) is particularly aligned and focussed upon the mechanics of the CoD process, i.e., the steps into, during and out of changing direction. CoDs has been used to describe preplanned CoD ability, without reference to a perceptual or decision-making element in the movement, being defined as "the ability to decelerate, reverse, or change movement direction and accelerate again" (Jones, Bampouras, & Marrin, 2009 p.4 check). For example, mechanical variables including braking and propulsive forces, impulses, and ground contact times have been measured and analysed to determine better CoDs performances (Dos'Santos et al., 2017).

Reflecting this broad focus, Bradshaw, Young, Russell, and Burge (2011) used a combination of timing gates and a video-based system to assess sections of CoD tasks (split step, shuffle & side-step). These included entry time, foot plant preparation time, approach time and exit time. Green, Blake, and Caulfield (2011b) identified a shorter ground contact and earlier leg extension at the knee during the CoD process in different classifications of rugby union players. As a consequence, particularly in team sports, there has been a clear focus in identifying the mechanical determinants of this CoD process.

When examining the kinematics of the CoD movement, specific variables of velocity or movement speed and lateral foot displacement have been evaluated in previous studies (Sayers, 2015; Wheeler & Sayer, 2010). Nimphius et al. (2017) alluded to the need for a better understanding of these kinematic factors; for example, body position, angle and velocity demands of the task, from both a qualitative and quantitative perspective. Centre of mass (CoM) velocity during CoD movements, and particularly while entering and leaving the CoD step i.e., CoDs has been previously identified as important to overall CoD performance (e.g., Dos'Santos et al., 2018; Green et al., 2011b; Nimphius et al., 2018). Explicitly, Green et al. (2011b) described the deceleration and reacceleration during a 45° CoD step, highlighting the importance of maintaining velocity throughout this crucial phase. Sayers measured CoM velocity, at varying distances from the point of direction change, to represent overall CoD performance. He indicated that measuring velocity over a distance of 1 m "helps discriminate CoD ability from high-speed linear running ability" (p. 2415). Comparing CoM velocity in preplanned and reactive CoD movements with overall PT has precedent in defining CoD technical performance.

Sasaki et al. (2011) stated that limited research had been undertaken to examine the relationship between the mechanics of CoD technique and CoD ability. Specifically, they reported that an optimal body lean might be linked to CoD performance. Spiteri et al. (2013) also suggested that "modified lower body positioning" (p. 646) would produce faster COD performances, with dynamic flexibility and balance also contributing (Čoh et al., 2018), while Wheeler and Sayers (2010) assessed the body orientation of participants during a preplanned and a reactive CoD task. They measured the foot displacement in both the anteroposterior and lateral directions, to examine the influence of body position on agility. Wheeler and Sayers found that adjustment in orientation in the step before the actual CoD step was significantly influential to overall PT.

4.1.5 Movement variability.

Preatoni et al. (2013) described how the importance of movement variability (MV) and coordination variability in the mechanical understanding of movements, are increasing areas of interest. While previously considered an artefact of coordinated movement, the benefits of examining MV have been promoted. MV is the variance in inter, but more importantly, intra-individual performance, Dos'Santos et al. (2017) stated that "MV reflects the inherent functional features of the neuromuscular system and may contain important information that should not be neglected." (p. 72). Debate surrounds ideal technique, i.e., whether such a concept exists, or whether good performance is as a consequence of different movement solutions for any particular situation or environment. Traditionally, variability has been perceived as counterproductive to performance. GMA, as represented by generic agility, may represent the background movement competencies that can be called upon in any situation. A broader and higher level of GMA affords a more thorough base of variations on which specific movement solution can be created. MV may be present and indicative of performers who can create a more extensive range of solutions to context-specific challenges. This adaptability, through modification and adjustment of an already established motor skill, has been identified as a benefit of variability (Dingwell, Cusumano, Cavanagh, & Sternad, 2001). Notably, performance MV has been described as functional changes of a coordinated movement that reflect its adaptability to context-specific solutions, rather than random noise or outcome variability (Preatoni et al., 2013). Wilson et al. (2008) specifically describe coordination variability as providing a degree of flexibility within systems to allow for perturbations to be accommodated.

Bosch (2010) discussed some relevant issues concerning MV and specificity. Explicitly, the concepts of attractors and fluctuators, where reducing the degree of freedom, in a movement, to create stable coordination tasks through identified attractors may conceptually align with GMA. Whereas, fluctuators relate to the variable elements in a movement which are adjusted for performance gains, akin to MV in high-level performers, and can be interpreted as a performer's adaptability. This adaptability could be conceptually linked to generic and specific agility, generic supporting the attractors, and specific agility allowing specificity to be applied and adapted for context-specific outcomes.

In summary, sport specific practice and training, as a function of sport or context-specific performance, is vital. However, assessing the usefulness of a GMA to support specific abilities, to optimise performance, requires further examination. Specifically, examining the relationship between generic and specific agility, via CoD movements may be beneficial. While technique analysis of these CoD movement in the form of assessing kinematic variables may enlighten the relationship with GMA, specifically examining body orientation and velocity during generic and specific CoD tasks.

4.1.4 Study aims.

Therefore, this study aimed to explore the link between CoD ability and GMA in a homogenous participant group of RL players, while also examining the mechanics of two CoD techniques. Participants were drawn from a youth RL population of under 16's scholarship squads. They all took part in the same development programme and were tested at the same point in the training cycle, which was early pre-season. Specifically, I compared performance on the WMAT with performances in a generic preplanned and a sport-specific reactive CoD task. I hypothesised that (a) GMA, as measured by WMAT, would correlate with a preplanned and reactive CoD task PT; and (b), that WMAT would predict PT on a preplanned and reactive CoD task. I also examined specific kinematics of the CoD event (CoD foot and pre-CoD foot) between preplanned and reactive CoD and compared them with PTs. I hypothesised that (a) kinematic variables would correlate with preplanned and reactive CoD task PTs; and (b), those kinematic variables would predict preplanned and reactive CoD task PTs. For this study, I interpreted the preplanned CoD (CoD_{pp}) task as a non-sport or context-specific agility movement. These preplanned movements are often used as agility training drills in applied practice. Whereas, the reactive CoD (CoD_r) task, involving a CoD in response to an external stimulus, is a representation of sport-specificity in utilising a reactive element. It should be noted that the original aim was to investigate the kinematic variables utilising a larger sample (n=30) to ensure the power of any statistical interpretation. However, in endeavouring to maintain ecological validity in data collection by testing on an outdoor 3G pitch this created issues with the 3-dimensional motion capture system. As this system uses reflected light and despite the use of an active filtering process (Qualisys, Goteborg, Sweden) the environmental condition (excessive sunlight) caused a number of markers (see section 4.2.2) not to be tracked. Therefore, the models for a number of participants were unusable, leaving 11 complete models that could be processed and analysed.

4.2 Method

4.2.1 Participants.

The sample consisted of 107 youth participants (mean ± SD; age: 16 ± 1 years; body mass: 73 ± 15 kg; height: 175 ± 7 cm) who were scholarship RL players. Using inclusion criteria, participants were deemed suitable to take part in the study if, they were, (a) free of significant injury for a period of three months prior to the commencement of the study, (b) physically active, i.e., they engaged in a minimum of 150 min of high-intensity activity over a week, and (c) familiar with agility type movements. Before testing each participant was required to attend one familiarisation session, where the testing protocols were explained and rehearsed. The participants read the description of the aims and objectives, risks, and basic procedures of the study and a Physical Activity Readiness Questionnaire was completed. Informed consent was gained from the parents/guardians of all participants as they were all classed as minors. The study was approved by the Faculty of Health and Life Sciences ethics committee at York St John University and also by the Business, Arts, Humanities and Social Science ethics committee at University of Central Lancashire.

4.2.2 Instrumentation.

This research design was a cross-sectional comparative study where participants undertook the WMAT (Campbell & Tucker, 1967), and a series of CoD_{pp} and CoD_{r} tasks each involving a single 45° CoD movement (see Figure 4.1). The outcome variable for both CoD tasks was the overall PT to complete the tasks. PT of the task was recorded using a timing system (Microgate, Switzerland) (see Figure 4.1). Kinematic variables were also measured for each CoD task; these included: velocity, acceleration, and lateral foot displacement.

CoD tasks.

For the CoD_{pp} task, each participant was positioned behind a start line. Using a self-paced start, they initiated their sprint from a static 2-point position. They maximally accelerated away from the start line changing direction after 7.44 m, The CoD point was identified by a target line marked on the floor, and further demarcated by two vertical poles 1 m apart. Following a taped line that was 45° to the left or right of the original sprint direction. The direction was dependent upon the participant's dominant leg. Participants completed the remaining sprint after changing direction by passing over a finish line.

For the CoD_r task, each participant was positioned behind a start line; using a self-paced start they initiated their sprint from a static 2-point position. They maximally accelerated away from the start line changing direction after approximately 7.44 m. Following a presentation of a stimulus, the participants changed direction at 45° to the left or right of the original sprint direction, and participants completed the remaining sprint after changing direction.

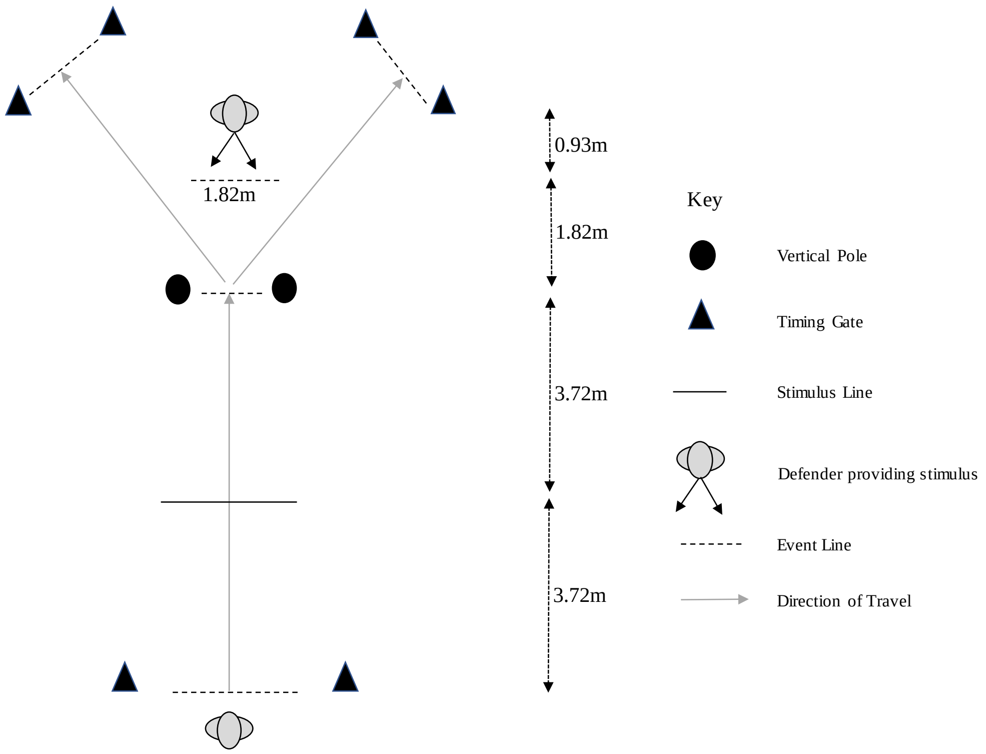

Figure 4.1. Adapted from Wheeler and Sayers (2010), data collection set-up for the CoD tasks

The stimulus was in the form of a defender simulating an RL defensive movement pattern; the stimulus was initiated when the participant crossed the stimulus line (see Figure 4.1) and was standardised by using one defender for all trials. This task required participants to traverse the opposite running line to the oblique movements of the defender, for example, if the defender moved to the participant's left, then they would react and step to the right and continue through the right side of the course. It should be noted that the defender was used as a reactive stimulus only and did not tackle the participants as they completed the reactive agility task.

The kinematic analysis (n = 11) examined the CoD for the step before the CoD (pre-CoD step) and then the CoD *step* (CoD step), defined as an outside cut. Predictor variables were collected between foot-strike and toe-off of the pre-CoD step and CoD step, as previously described by Wheeler and Sayers (2011). These measures were used to determine the velocity of the CoM in the sagittal (X direction) and frontal (Y direction) planes (see Figure 4.2). Foot displacement relative to the CoM, was also calculated (see Figure 4.2). Landmarks representing the CoM was placed on the greater trochanter of the femur in the sagittal plane and equidistant between the left and right posterior superior iliac spine in the frontal plane. Measurements were taken at foot-strike and toe-off of each pre-CoD step and CoD. These kinematic variables were measured using a 3-dimensional movement analysis. An 11-imager motion capture system (Qualisys, Goteborg, Sweden) was set up and calibrated to record the CoD tasks (see Figure 4.1). Imagers were positioned in a semi-circular configuration to ensure adequate coverage of the CoD movements. Retroreflective markers (4M markers) were placed on the participants identifying appropriate anatomical landmarks for identification of segments, as well as clusters for tracking segments (located on the anterior and posterior superior iliac spine, greater trochanter, thigh cluster, medial and lateral knee, shank cluster, medial and lateral ankle, calcaneus, talus and metatarsals one and five). These markers were affixed either directly to the skin using superglue (Loctite, Ohio, USA) and double-sided sticky tape or attached to cluster plates and secured by bandages (mediwrap). The tracked markers were automatically digitised (500 Hz) (Qualisys Track Manager, Goteborg, Sweden), downloaded and analysed using a modelling software package (C Motion, Maryland, USA).

WMAT.

The participants completed the WMAT (Campbell & Tucker, 1967), the protocols are detailed in Appendix B. To recap, this test consists of, (a) an agility run, assessed by the total time to complete the course; (b) a standing broad jump, measured using a measuring tape as the horizontal distance covered; (c) an alternate handball toss, with the duration of the test measured with a stopwatch and number of catches recorded by a single researcher; (d) a seated basketball throw measured using a measuring tape, and assessed as the horizontal distance from the throw line to initial landing point in the basketball throw.

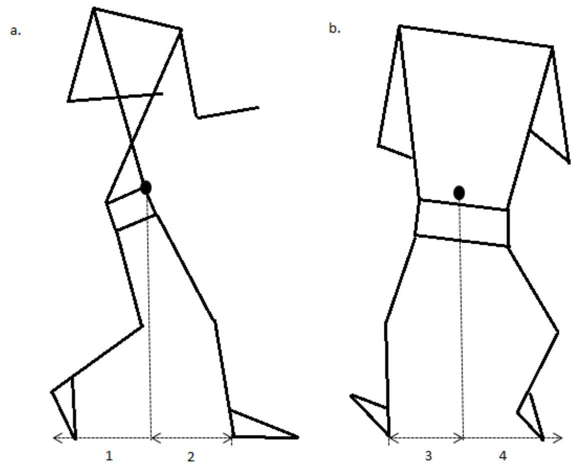

Figure 4.2. Adapted from Wheeler and Sayers (2010) foot displacement relative to the landmarks representing the CoM (●) (a) sagittal plane view of anteroposterior foot displacement (b) frontal plane view of mediolateral foot displacement. 1. Posterior foot displacement (negative value), 2. Anterior foot displacement (positive value), 3. Lateral foot displacement (positive value) & 4. Lateral foot displacement (negative value).

4.2.3 Protocol.

Each testing session began with a standardised 10 min dynamic warm-up, including running, bounding and dynamic stretching, followed by the respective experimental protocol. Participants completed three CoD_{pp} trials and six CoD_r trials (three trials for both right and left directions) with the order and condition randomised, via a random number generation technique, throughout testing. The best CoD_{pp} and CoD_r PT were used for further analysis. Testing occurred over two different sessions separated by one week, thus ensuring that adequate rest was allowed between WMAT and CoD tasks. Participants completed the four component tests of the WMAT as a circuit, and at least 15 min separated each test. Separately, kinematic variables of performance were collected to allow for technical analysis of the CoD tasks. This technical analysis was completed on a sub-group of the original sample (*n* = 11). All testing took place on an outdoor 3G surface with participants wearing shorts, skin-tight tops, and rugby boots, except for the alternate handball toss which took place indoors.

4.2.4 Data analysis.

Statistical analyses were performed with SPSS Version 24 (IBM Corporation, Armonk, NY, USA). Individual WMAT scores were processed as in Chapter Three (see Section 3.2.4). Preliminary analyses for normality (Kolmogorov-Smirnov) and homoscedasticity were performed. In the first stage of analysis, (a) Pearson's correlation coefficients (*r*) assessed the strength of association between WMAT and preplanned and reactive CoD, respectively; (b) linear regressions assessed WMAT's predictive ability on preplanned and reactive CoD PT. The two outcome variables used were PT in the preplanned and the reactive CoD tasks, WMAT was the predictor variable; (c) a repeated measure *t*-test assessed the difference in CoD_{pp} and CoD_{r}.

In the second stage, (a) *r* values assessed the strength of association between preplanned and reactive CoD kinematic variables and preplanned and reactive CoD PT, (b) two stepwise multi-regression analyses were used to investigate the predictive capacity of kinematic variables on both preplanned and reactive CoD PTs, respectively. Variance inflation factor (VIF) was assessed using multicollinearity analyses as recommended by Liu and Chan (2011). This VIF was to assess how much the variance of the estimated regression coefficients was increased because of collinearity. The diagnostics identified a non-significant correlation amongst treatment variables as the VIF rating was below 10.00 (Pallant, 2010). Significant predictor parameters were correlated with WMAT scores. The *r* values were interpreted according to the values suggested by Cohen (1992) where 0.1 = small, 0.3 = moderate and 0.5 ≥ large when using a correlation coefficient. Statistical significance of 95% was used ($p < .05$) for all tests, including entry into the regression model.

4.3 Results

4.3.1 Preliminary results.

Three kinematic variables were found to be skewed. CoD_r foot on X displacement was positively skewed (z = 2.46), CoD_r foot on Y displacement (z = -0.04) and CoD_r toe off X displacement (z = -2.20) were negatively skewed; accordingly, all were square transformed to achieve normality. All other data were normally distributed and homoscedastic. VIF values for the linear regression statistics for CoD_{pp} and CoD_r were both 1.0, as they were for the multiple regression statistics. The standardised distribution data for CoD_{pp} and CoD_r PT are presented in Figure 4.5 and 4.6.

4.3.2 Stage one: correlations and linear regressions.

Table 4.1.

Descriptive statistics and, repeat sample *t*-test, Pearson's correlation coefficient (*r*) for WMAT, CoD_{pp} and CoD_r PT

Variables	**M (SD)**	**95% CI**	**WMAT (mean sigma score)[a]**
CoD_{pp} time (s)	2.20 (0.15)	2.1, 2.23	-.61**
CoD_r time (s)	2.26 (0.16)[b,c]	2.23, 2.30	-.64**
WMAT (mean sigma score)	58.70 (11.02)	56.59, 60.81	

[a] N = 107
[b] = Significant difference in mean CoD times, *p* < .01
[c] = Significant association between CoD_{pp} and CoD_r, *p* < .01
** p < .01 (2-tailed)

Table 4.2.

Variance (R^2) between predictor WMAT and CoD_{pp} time, fit of model (*F*), unstandardised predictor value (B) and standardised predictor value (β)

Variable	R^2	***F***	**B**	**β**
WMAT (mean sigma score)[a]	.37	62.59 (1,106)**	-0.01	-.61**

Note. Outcome variable = Preplanned CoD time
[a] N = 107
** *p* < .01

Table 4.3.

Variance (R^2) between predictor WMAT and CoD_r time, fit of model (F), unstandardised predictor value (B) and standardised predictor value (β)

Variable	***R*²**	***F***	**B**	**β**
WMAT (mean sigma score)[a]	.41	72.52 (1,106)**	-0.01	-.64**

Note. Outcome variable = Reactive CoD time
** $p < .01$
[a] N = 107

Table 4.1 indicates that mean CoD_r performance was significantly slower that mean CoD_{pp}, with a mean difference of 0.06s. WMAT had a large negative association with CoD_{pp} ($r = -.61$, $p < .01$) and CoD_r performance ($r = -.64$, $p < .01$) and a significant negative relationship exists between WMAT and both general and specific CoD tasks. Table 4.2 and 4.3 define significant models when WMAT predicts CoD_{pp} PT (F (1,106) = 62.59, $p < .01$) and CoD_r PT (F (1,106) = 72.52, $p < .01$).

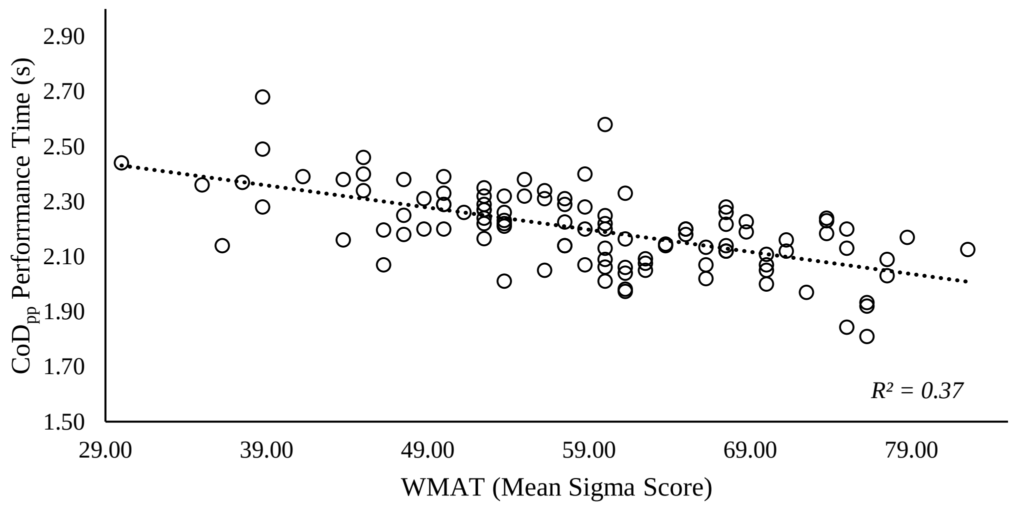

Figure 4.3. Variance in WMAT with respect to CoD_{pp} PT

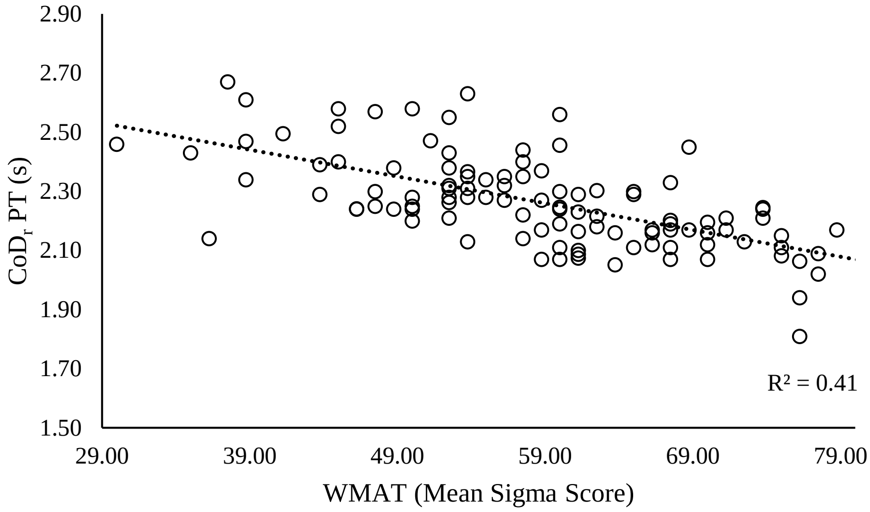

Figure 4.4. Variance in WMAT with respect to CoD_r PT

The shared variance between WMAT and CoD_{pp} (37%) and CoD_r (41%) performance, respectively is presented in Figure 4.3 and 4.4. The mean velocities and foot displacements during the pre-CoD step and CoD step foot contacts are presented in Table 4.4. Velocity in the sagittal plane at toe-off is lower in in CoD_{pp} (5.19 $m \cdot s^{-1}$) task than the CoD_r task (5.41 $m \cdot s^{-1}$), whilst this is reversed in the frontal plane (toe-off preplanned CoD = 2.18 $m \cdot s^{-1}$; toe-off preplanned CoD = 1.67 $m \cdot s^{-1}$).

Correlation coefficients between preplanned and reactive kinematics and CoD_{pp} and CoD_r PTs, respectively, are presented in Table 4.5. Only three significant associations were found to exist, (a) pre-CoD step toe-off velocity (r = -.67, $p < .05$), (b) CoD step foot-on velocity (r = -.71, $p < .05$), and (c) CoD step toe-off velocity (r = -.69, $p < .05$) in the sagittal plane. These all have a large negative association with CoD_{pp} PT. All other correlations were non-significant. The pre-CoD step toe-off velocity had a shared variance with CoD_{pp} PT of 45%.

4.4.3 Stage two - correlations and stepwise multiple regressions.

Table 4.4.

Descriptive statistics for CoD kinematic variables

Variable	**CoD_{pp} Task[a]**				**CoD_r Task[a]**			
	Pre-CoD step		CoD step		Pre-CoD step		CoD step	
	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI
X Foot-on Velocity ($m \cdot s^{-1}$)	5.33 (0.33)	5.11, 5.56	5.37 (0.35)	5.13, 5.61	5.24 (0.28)	5.05, 5.43	5.36 (0.30)	5.16, 5.56
Y Foot-on Velocity ($m \cdot s^{-1}$)	0.91 (0.24)	0.75, 1.07	0.78 (0.41)	0.51, 1.05	0.37 (0.29)	0.18, 0.57	0.39 (0.19)	0.26, 0.52
X Toe-Off Velocity ($m \cdot s^{-1}$)	5.45 (0.46)	5.14, 5.76	5.19 (0.51)	4.84, 5.53	5.19 (0.50)	4.86, 5.53	5.41 (0.26)	5.24, 5.59
Y Toe-Off Velocity ($m \cdot s^{-1}$)	0.93 (0.24)	0.78, 1.09	2.18 (0.64)	1.75, 2.61	0.37 (0.20)	0.23, 0.51	1.67 (0.61)	1.27, 2.08
X Foot-on Displacement (m)	-0.11 (0.10)	-0.18, -0.04	-0.24 (0.11)	-0.32, -0.17	-0.13 (0.11)	-0.20, -0.05	-0.14 (0.23)	-0.29, 0.02
Y Foot-on Displacement (m)	0.06 (0.10)	-0.01, 0.12	0.37 (0.05)	0.34, 0.41	0.02 (0.12)	-0.06, 0.10	0.02 (0.39)	-0.24, 0.28
X Toe-off Displacement (m)	0.27 (0.19)	0.14, 0.40	0.35 (0.06)	0.31, 0.39	0.23 0.16)	0.13, 0.34	0.26 (0.25)	0.09, 0.43
Y Toe-off Displacement (m)	0.12 (0.13)	0.03, 0.21	0.56 (0.08)	0.51, 0.61	0.02 (0.10)	-0.05, 0.09	0.04 (0.50)	-0.29, 0.38

Note. X = anteroposterior direction, Y = lateral direction
[a]$n = 11$

Table 4.5.

Pearson's correlation coefficients (*r*) for kinematic variables of CoDpp and CoD_r PTs

Variable (preplanned)[a]	**CoD_{pp} PT (s)**[a]	**Variable (reactive)**[a]	**CoD_r PT (s)**[a]
X Pre-CoD step Foot-on Velocity ($m·s^{-1}$)	-.47	X Pre-CoD step Foot-on Velocity ($m·s^{-1}$)	-.13
Y Pre-CoD step Foot-on Velocity ($m·s^{-1}$)	.29	Y Pre-CoD step Foot-on Velocity ($m·s^{-1}$)	-.09
X Pre-CoD step Toe-off Velocity ($m·s^{-1}$)	-.67*	X Pre-CoD step Toe-off Velocity ($m·s^{-1}$)	.01
Y Pre-CoD step Toe-off Velocity ($m·s^{-1}$)	.18	Y Pre-CoD step Toe-off Velocity ($m·s^{-1}$)	-.15
X CoD step Foot-on Velocity ($m·s^{-1}$)	-.71*	X CoD step Foot-on Velocity ($m·s^{-1}$)	.00
Y CoD step Foot-on Velocity ($m·s^{-1}$)	.54	Y CoD step Foot-on Velocity ($m·s^{-1}$)	.48
X CoD step Toe-off Velocity ($m·s^{-1}$)	-.69*	X CoD step Toe-off Velocity ($m·s^{-1}$)	-.18
Y CoD step Toe-off Velocity ($m·s^{-1}$)	.42	Y CoD step Toe-off Velocity ($m·s^{-1}$)	-.29
X Pre-CoD step Foot-on Displacement (m)	-.31	X Pre-CoD step Foot-on Displacement (m)	-.05
Y Pre-CoD step Foot-on Displacement (m)	.34	Y Pre-CoD step Foot-on Displacement (m)	.09
X Pre-CoD step Toe-off Displacement (m)	-.10	X Pre-CoD step Toe-off Displacement (m)	.17
Y Pre-CoD step Toe-off Displacement (m)	.49	Y Pre-CoD step Toe-off Displacement (m)	.05
X CoD step Foot-on Displacement (m)	-.17	X CoD step Foot-on Displacement[b] (m)	.00
Y CoD step Foot-on Displacement (m)	.27	Y CoD step Foot-on Displacement[b] (m)	-.07
X CoD step Toe-off Displacement (m)	-.43	X CoD step Toe-off Displacement[b] (m)	-.60
Y CoD step Toe-off Displacement (m)	.43	Y CoD step Toe-off Displacement (m)	-.04

Note. X = anteroposterior direction, Y = lateral direction
[a] $n = 11$
[b] square transformed
* $p < .05$ (2-tailed)

Table 4.6.

Descriptive statistics for CoD_{pp} and CoD_r PTs during kinematic analysis

CoD Test	**Mean (SD)**	**95% CI**
CoD_{pp} PT (s)	2.02 (0.08)	1.96, 2.07
CoD_r PT (s)	2.16 (0.10)	2.09, 2.22

N = 11

The mean CoD PTs and descriptive statistics recorded during the kinematic analysis (stage two) are presented separately in Table 4.6.

Table 4.7.

Variance (R^2) between all preplanned kinematic variables and CoD_{pp} time, fit of model (F), unstandardised predictor value (B) and standardised predictor value (β)

Predictor	$\boldsymbol{R^2}$	$\boldsymbol{F}$	**B**	**β**
CoD step foot-on velocity (X) in CoD_{pp} task[a]	.51	9.21 (1,9)*	-.17	-.71*

Note. Predictor variable = Preplanned CoD time
[a] N = 11
* $p < .05$

The stepwise multiple regression performed on the CoD_r data, modelling reactive kinematic variables and CoD_r PT, did not produce a significant model. While a regression model for the preplanned kinematics variables and CoD_{pp} PT was significant ($F(1,9) = 9.21$, $p < .05$), only 1 variable proved a significant predictor (X CoD step foot-on velocity, $\beta = -.71$, $p < .05$). As the only predictive factor CoD foot-on velocity in the sagittal plane shared a 51% variance with CoD_{pp} PT (see Figure 4.5).

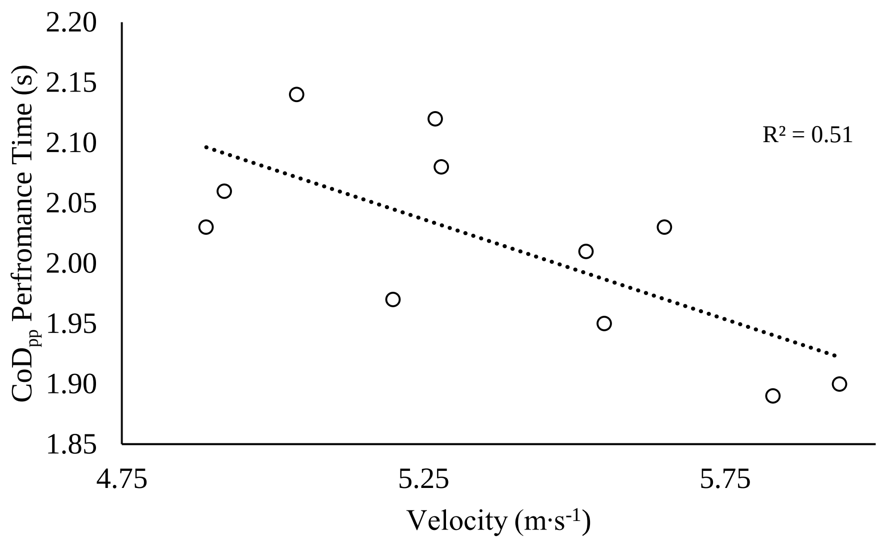

Figure 4.5. Relationship of CoD step foot on velocity (X) with CoD_{pp} PT

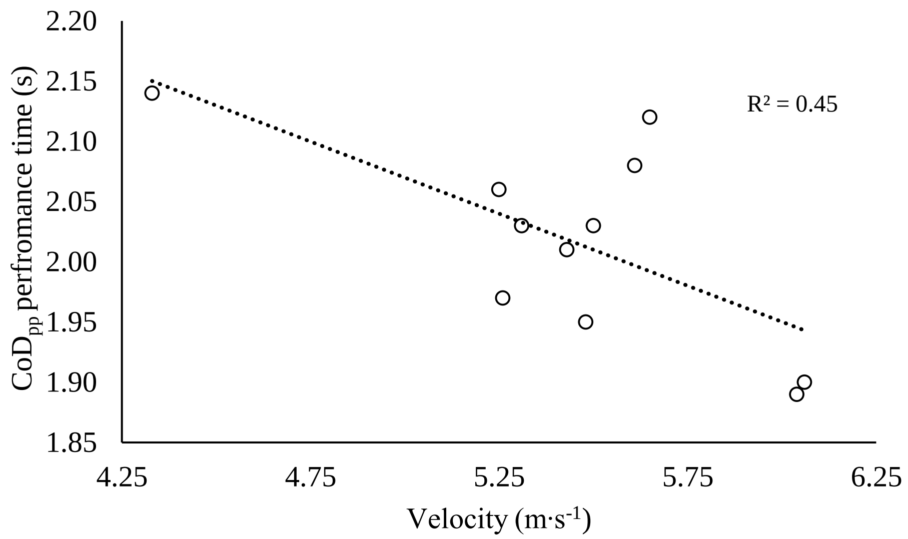

Figure 4.6. Relationship of pre-CoD step toe off velocity (X) with CoD_{pp} PT.

4.4 Discussion

I hypothesised that GMA, as measured by WMAT, would correlate with a preplanned and reactive CoD task PT and that WMAT would predict PT on a preplanned and reactive CoD task. I also hypothesised that kinematic variables would correlate with preplanned and reactive CoD task PTs, and kinematic variables would predict preplanned and reactive CoD task PTs. Results from this study indicated that performance on the WMAT significantly predicts performance on both preplanned and reactive CoD tasks, suggesting that GMA influences performance in generic *and* specific agility. One kinematic variable from those analysed predicted performance on the CoD tasks, indicating that variation in technique when performing CoD tasks is prominent. This variation is irrespective of performance level and may indicate adaptability in performers (Dingwell et al., 2001). Consequently, the first hypotheses, that GMA, as measured by WMAT, would correlate with CoD_{pp} and CoD_r tasks PT and WMAT would predict PT on a CoD_{pp} and CoD_r task, was accepted. The hypotheses that kinematic variables would correlate with CoD_{pp} and CoD_r task PTs and kinematic variables would predict CoD_{pp} and CoD_r task PTs could be partially accepted with caution, based upon the impact of a small sample size.

The importance of GMA, as measured by WMAT, has been established (Chapter Three), with evidence indicating that it is strongly associated with physical attributes and playing qualities that are valued by performers and coaches alike (Till, Tester, Jones, Emmonds, & Fahey, 2014; Kirkpatrick & Comfort, 2013). Moreover, the results from this study provide further data that GMA can play a central role in athlete development, as it potentially provides the underpinning for context-specific movements. These underpinning qualities that are holistically represented by GMA are linked to the skills required in more sports-specific contexts and influence the adaptability or variability employed to solve specific movement challenges. Hands et al. (2018) support the findings of this study in extolling the virtue of GMA, though this is contrary to others who highlight the importance of sports specificity (e.g., Drowatzky & Zuccato, 1967; Thorndike, 1914, or Zemková, 2017).

4.4.1. Generic and specific agility.

The mean difference in the PT (0.06s, ES = .19) between CoD_{pp} and CoD_r was significant, as identified in previous studies (Gabbett et al., 2008; Henry et al., 2011: Morland, Bottoms, Sinclair, & Bourne, 2013). Green et al. (2011a) indicated that these types of movements had been shown to discriminate levels of performance in sporting environments. The difference in performance in these two tasks was as a result of the reactive elements, as previously identified as the speed of decision making (Zemková & Hamar, 2018). This difference provides support for my interpretation of CoD_{pp} as representing *generic agility* and CoD_r having a greater game-context focus, and therefore aligning with the concept of *specific agility* (see Chapter Two). Furthermore, the link between GMA, generic agility and specific agility provides further insight into the consideration that GMA is a singularity. GMA supports the specific agility requirements of complex skills, with the practice of generic agility movement patterns, supported by an array of sub-capacities or internal and external factors (Čoh et al., 2018). Oliver and Meyers (2009) reported smaller mean differences between CoD performance, than in this study. This discrepancy may be accounted for by the different types of stimulus. As a real stimulus, as opposed to light, was utilised it may provide more opportunity to read the required direction change from the person presenting the stimulus (Sheppard et al., 2006), and therefore facilitate a faster reactive CoD PT. Morland et al. (2013) confirmed that reactive ability has a greater sport-specific influence and its role in agility is becoming better understood. They described how better performers could react to sport-specific cues more readily in a reactive agility test, than lower level performers

Despite the significant difference in PTs in CoD_{pp} and CoD_r, they are seemingly underpinned by common elements and are highly related ($r = 0.77$, $p = < .01$). I suggested (see Section 4.1) that general and specific CoD have shared physical elements (Oliver & Meyers, 2009) and that these are fundamental to motor learning and subsequent, appropriate development of skill (Giblin et al., 2014; MacNamara, et al., 2015). Similar to this study, Oliver and Meyers described a shared variance of 85% between preplanned and reactive agility tests, yet the mean times were significantly different. Here the shared variance, between CoD_{pp} and CoD_r was 59%, though less than previously reported it was sufficiently large to consider that the two share underpinning qualities, that influence performance.

4.4.2. The relationship between GMA and CoD performance.

The level of a performer's GMA predicted their capability in both preplanned and reactive agility movements. GMA as measured by the WMAT predicted performance on a CoD_{pp} task ($F(1,106) = 62.59$, $p < .01$), with an R^2 of .37. Participants' predicted CoD_{pp} PT was equal to 2.67 - .01 (WMAT) when WMAT is measured as a mean sigma score (see Table 4.2). WMAT also predicted performance on a CoD_r task ($F(1,106) = 72.52$, $p < .01$), with an R^2 of .41. Participants' predicted CoD_r PT was equal to 2.79 - .01 (WMAT) when WMAT was measured as a mean sigma score (See Table 4.3). Further to this, both CoD_{pp} ($r = -.61$, $p < .01$) and CoD_r ($r = -.64$, $p < .01$) have large correlations with WMAT (see Table 4.1). Although the shared variance of 37% (CoD_{pp}) and 41% (CoD_r) may be interpreted that WMAT scores, as a singular entity, play a lesser role in influencing the outcomes on these CoD performances (see Figure 4.3 and 4.4). As previously discussed, these lower values are not evidence that GMA is a significant influence on CoD. Overall, the findings support the suggested relationship between GMA, generic agility and specific agility, signifying that a broader, more established GMA base can facilitate better outcomes in general and specific sporting performances.

Despite previous evidence suggesting that some essential physical qualities do not transfer from preplanned to reactive or sporting environments (Simonek et al., 2016), these findings indicate that the shared variance (see Table 4.2 & 4.3) WMAT has with both the CoD tasks suggests common elements required for successful performance in either are represented as a GMA. This shared variance is more in alignment with Spiteri et al. (2015) who have also demonstrated commonality in underlying physical capacities such as strength components. The manifestation of these shared elements may be in the form of movement foundations (Burton & Rodgerson, 2001) which require basic physical capacities, applied in a manner which allows for a more specific, narrower movement solution. Burton and Rodgerson described these as movements skill sets. As a consequence of the positive predictive relationship of WMAT, those individuals that possess a better GMA perform faster on both CoD tasks which indicates the potential usefulness of developing and maintaining a reasonable level of GMA and is indicative of common physical attributes which support both types of CoD movements. While it has been previously suggested (Henry et al., 2016) that specific measures of strength do not relate to CoD_r performance and that other qualities such as balance, coordination and skill may be defining factors in agility movements. Interpreting Henry et al. (2016) findings, in isolation, that singular attributes or qualities do not facilitate agility performance can lead to obfuscation in applied practice. Such a reductionist perspective can foster a philosophy that specific qualities either do or don't impact specific performances, with little consideration that multiple, simple capacities may have a collective influence on a wide range of performance outcomes. That is, each separate physical ability, neuromuscular quality, coordinative pattern may not directly relate or transfer to skilled performance, but their collective contribution may still be significant. The ability of a performer to amalgamate these various qualities and capitalise on them in unique situations suggests a GMA. This GMA or athleticism is influential and is wide-ranging, from more basic movement qualities to its impact in highly specific and contextualised complex skills. It should be noted that WMAT as a representation of GMA does indeed use the evaluation of four individual physical qualities and amalgamates them to produce a singular GMA value.

It is interesting to note that Edwards et al. (2018) discussed the philosophical assumptions that are often made about developing a scientific concept. Stating that "failures to acknowledge and address philosophical assumptions are at the heart of a number of tensions and crises within sport and exercise research" (p. 661). Regarding the conceptualisation of GMA and specificity, these concepts may benefit from a future discussion around the assumptions that underpin them. It may turn out that the difference between the GMA and specificity *perspectives*, being more associated with philosophical differences rather than actual difference (e.g., Jeffreys, 2006).

4.4.3 Kinematic factors.

In examining the mechanics of the two CoD tasks (Wheeler & Sayers, 2010), the aim was to assess if commonality in kinematic variables resulted in an optimum technique for a 45° CoD and therefore influence PT. This analysis was undertaken on a sub-group of the total participant group, n = 11, and were for convenience drawn from a particular group of scholarship players. It is acknowledged that the sample size was small and this may have impacted the power of the subsequent statistical analysis, this was due to environmental condition effecting participant data (n=19) which was unusable (see section 4.1.4). It should be noted that this group did possess faster PT in both CoD_{pp} and CoD_r compared with the whole participant group (see Table 4.6). The data presented in Table 4.7 shows that CoD step foot-on velocity in a sagittal plane (X) predicts performance on a CoD_{pp} task (F (1,9) = 9.21, $p < .05$). Participants' predicted

CoD_{pp} PT is equal to 2.46 - .51 (WMAT) seconds when CoD step foot-on velocity in a sagittal plane (X) is measured as $m{\cdot}s^{-1}$. Though this sagittal plane foot contact velocity of the CoD step foot was the only predictor of CoD_{pp} performance, both sagittal plane preplanned pre-CoD step toe off velocity ($r = -.67$, $p < .05$) and CoD step toe off velocity ($r = -.69$, $p < .05$) significantly associated with CoD_{pp} PT (see Table 4.5). These finding indicated that the ability to possess high velocity in the foot contact before changing direction, thus maintaining velocity, was a significant technical factor (Wheeler & Sayers, 2010). Previous research examining the kinematics of CoD performance (Dos'Santos et al., 2017) has also demonstrated the importance of the pre-CoD step in influencing performance. They also found a strong relationship with CoD step foot on velocity ($r = -.71$, $p < .05$) and CoD_{pp} PT. The shared variance of 51% (see Figure 4.5.) that CoD step foot-on velocity in a sagittal plane has with CoD_{pp} is indicative of the noteworthy influence high velocity during the CoD process has on performance outcomes in CoD. The relationship between maintaining velocity and deceleration into CoD is an intriguing one. In their review Dos'Santos et al. (2018) described CoD angle and entry velocity as key determinants in the mechanical outcomes in a CoD task. In a 45° CoD, as in this study, Dos'Santos et al. indicated that maintaining velocity into the CoD step is acceptable, as opposed to larger angled CoDs that required more decelerates in preparation of the final CoD step. The findings of this study suggest that pre-CoD step toe off velocity (X) had a significant relationship with CoD_{pp} PT with a shared variance of 45% (see Figure 4.5), proposing that the better performers maintained a higher velocity into (pre-CoD step) and during (CoD step) the preplanned CoD event.

No other variables in either the preplanned or the reactive CoD tasks predicted or significantly associated with overall PT (see Table 4.5). As the ability of the measured kinematic variables to predict CoD performance was poor, this might indicate that there is a high degree of variability in some of the underlying mechanics of these particular CoD tasks. The faster participants, who are associated with higher GMA, did not demonstrate a regular pattern while performing CoD_{pp} and CoD_r movements. This lack of consistency may be as a consequence of MV. I propose that generic agility may be the defining factor that is influencing performance on these general and sport-specific CoD tasks, allowing for the application of movement solutions that best enables the performer to achieve in the task. The absence of significant findings suggests that the better performers undertake these tasks in a less consistent technical manner, i.e., there is variation in their movement outcomes. This variability in technique indicates that MV, supported by generic agility, allows for the best performance outcome to be produced irrespective of how it is achieved. This variability highlighted a contemporary but obfuscated view of agility that GMA and specific agile techniques are the same entity when these results indicate that this is not the case. There are different movement solutions and or movement techniques in the CoD tasks, as highlighted by the absence of any significant predictors amongst the various kinematic parameters (other than CoD step foot-on velocity in a sagittal plane has with CoD_{pp}). However, it is proposed that the underpinning neuromuscular attributes that allow for this variation should be expected to align with GMA. This suggests that a good GMA is an advantage when adapting to specific performance outcomes, regardless of the technical solution used. It should, therefore, be emphasised, that despite this individual variation of movement solutions in the CoD tasks, those athletes that have better GMA consistently perform better on CoD tasks.

4.4.4 The role of MV.

The presence of variability in these findings suggests that better GMA performers may be superior at transferring their neuromuscular abilities into more context-specific skilled performances and be more able to adapt to these challenges.

The performers' capacity to transfer previous learning and find flexible neuromuscular solutions to new skills is facilitated as a consequence of better GMA (see Chapter Six). Though the debate continues with regards to the importance and significance of movement generality or specificity, concerning performance outcomes and transferability, data here indicates that GMA does relate positively to context-specific movement patterns. This is despite research into the specificity of motor learning supporting the concept of specific practice, for examples Thorndike's (1914) early identical elements theory and, a more recent interpretation by Bosch (2010) of his approach to MV related to de-centralised control. Preatoni et al. (2013) described the role of MV in sporting performance as being unclear, stating "the information MV may provide and the possible relationship between MV and performance, MV and the acquisition/development of motor skills, and/or MV and injury factors" (p. 70) still need investigating. Further to this, Dos'Santos et al. (2017) found that the CoD variables they measured demonstrated low reliability within sessions, MV, as opposed to signal noise, attributed as the reason. Consequently, variation in individual techniques, when qualitatively observed or quantitatively measured, can be considerable in CoD performance. For example Sayers (2015) reported a decrease in inter and intra reliability when CoDs was measured over shorter distances (< 10 m) during a CoD task, suggestive of an increase in MV while performing the actual CoD manoeuvre. It has been shown that higher levels of performers can accommodate and manipulate variability in movement solutions, to reach the desired outcome (Hiley et al., 2013). The U shaped relationship identified by Wilson et al. (2008) is also seen in the participants in this study, being classified as higher standard performers. In describing the relationship between MV and motor learning they identified considerable movement variation in early developmental stages, changing to low MV in more performers become more competent, and finally, elite performers benefiting from being able to utilise high variability in solving movement outcomes. The issue of MV was confirmed in these findings, that high standard performers employed greater MV in specific movement outcomes.

Neurological plasticity may, directly and indirectly, influence the adaptability and potential for MV in producing specific movement solution (see Section 2.5.1). The plasticity of the neurological system may facilitate the ability to produce successful movement outcomes with a high degree of MV and the ease in which an individual can adapt to novel challenges. As discussed, the ability of the neurological system to learn, re-learn, and adapt is significant, facilitated by the flexibility within a neural network to re-route and re-establish control various systems (Andriyanova & Lanskaia, 2014). This adaptability with the neurological system is discussed further in Chapter Six.

The simplicity of the WMAT.

Historically, GMA or motor ability assessments have been a standard tool used in talent identification contexts (Ibrahim, 2009). The concept of identifying and measuring underlying traits to express giftedness and athletic potential is standard practice, despite the controversy as to whether these are specific and individual abilities or more general ability. Concerning the historical use of GMA assessments to support the discrimination or classification of performers, the evidence here supports the practice of employing such tests for identifying potential talent, related to agility movements in RL. Contrary to this Morland et al. (2013) explained that "by removing the link between our perceptions and actions (i.e., the sports specificity) agility tests appear to become unable to discriminate reliably and repeatedly between playing standards which is one of the central aims behind testing." (p. 518). However, there are seemingly opportunities to re-visit and capitalise upon GMA for talent Identification. There is a link here to a coaches' desire to produce composite scores which may be used as a holistic description of physical capability of a performer. This type of assessment could be interpreted as evaluating generic agility and its contribution to specific performance (Burton & Rodgerson, 2001). Though it should be highlighted that Morland et al. (2013), with regards to CoD speed, were clear that preplanned tests did not differentiate performers at different competition levels and therefore was not a good indicator of the context-specific sports skill. The issue of type and nature of testing in talent identification continues to be a divisive area of study (Nimphius et al., 2018).

WMAT constitutes several assessments of closed skills; however, the findings here reveals that the open environment of the reactive CoD task (Čoh et al., 2018) is closely aligned to the concept of a GMA. Whereas in past research tasks specificity may have been justified due to low inter-correlation between assessment elements, or between general motor tasks and specific skills. These data strongly suggest that general athleticism or movement competency does influence higher-order motor performance, which tend to be more open skills

Accordingly, these results raise several important issues about the importance of GMA, its contribution to agility-based movements and the impact it has on the level of performance. Previous researchers have continued to debate whether GMA exists (Henry, 1958; Hands et al., 2018), in preference to the theory of specificity, whereby specific motor competencies are said to be unrelated (Ellison et al., 2017). The results here suggest the contrary when utilising a traditional measure of GMA, performance on agility-like movements strongly correlate. It should be reiterated that assessment of GMA when using WMAT, does provide a broad yet straightforward summary of separate motor abilities: standing broad jump, agility run, basketball throw and alternate handball toss, and it is these four abstract abilities that are represented in the total WMAT score. Thus, the critical point remains, that this GMA assessment does predict performance on sport-specific movements, and yet can be described as representing a GMA.

4.4.5 Chapter summary.

With regards to my construct of agility, GMA can be interpreted as to the way in which agility, both generic and specific, can be operationalised, through general and reactive CoD movements. The results here ostensibly re-enforce the proposed alignment of generic agility with GMA, as well as its important relationship with specific agility. This GMA is associated with the capability of these participants to draw upon a range of capacities that underpin performance (see Section 2.3.1). However, each of these capacities can work over an extended range to allow for overall variations in a movement to create successful skilled outcomes. For example, working over an extended range might refer to the throwing of an object with a variety of release angles, different release velocities, and different joint orientations. Thereby challenging the range over which muscle activation occurs, engaging a different combination of prime movers, broadening the afferent sensory information, extending the range over which eccentric actions occur (Chaabene, Prieske, Negra, & Granacher, 2018), promoting high angular velocities of multiple joints and developing integration of perceptual-motor abilities (Barnett, Stodden, et al., 2016). If MV is underpinned by a wide range of specific capacities that can effectively work over an extended range of their functionality, then this interpretation of GMA would be a singular entity that summarily represents these separate capacities and attributes, and their performance. Formerly stated, therefore, the discussion as to whether a GMA exists may be a matter of perspective. To reiterate, separate capacities have been viewed as specific and individual, from a reductionist theoretical perspective, that specificity is essential for transfer. Alternatively, a more holistic approach is where the perceived representation of an individual's athleticism represents a package of underlying abilities. Feasibly these different options are merely points of view rather than real theoretical differences, and the philosophical assumptions of both should be considered in the future.

If the evidence is supportive of GMA predicting and relating to generic and specific agility, then the implications for training and development of GMA should be examined. The potential for, and study of, this training effect over time is a novel and innovative interpretation of assessing and developing GMA which has not been fully considered previously in youth athletes. Therefore, longitudinal and developmental inference forms the investigation that was undertaken in Chapter Five.

Chapter Five

How Does it Develop? Exploring Longitudinal Changes in GMA

5.1 Introduction

Previous chapters have attempted to establish the importance of GMA and offered empirical evidence for its relationship to essential elements of talent development, including players' possession of desired physical and skill factors. I now wish to examine how GMA might be developed, specifically whether it requires specific attention in an academy environment or is a factor which would emerge from generic motor activity.

Developing and attaining motor competence, have been shown to be important in both influencing future physical activity and impacting success in sport-specific performance (Stodden et al., 2008). Despite this how GMA might be developed longitudinally to affect PL, PE and specific measures of general and specific agility performance have not been thoroughly investigated. The roles of PE (MacNamara et al., 2011), lifelong PL (Robinson et al., 2015) and AD models in the development of motor competency (Gulbin, Croser, Morley, & Weissensteiner, 2013) are established and considered vital to underpin skilled performance. Their role in promoting and developing motor competence in children, youths, and adults, to encourage and enable health-related activities for long-term benefits, should not be underestimated. It would be useful to examine how each interacts with or relate to GMA to effect longitudinal change.

I decided to examine the differential impact of specific training and more general activity-based programmes on GMA and a related construct, namely CoD. Before highlighting the results of this study, it is important to review some relevant areas of theoretical concern, for example, AD programmes in developing motor competence, the importance of motor competence in PL, and the role of PE.

5.1.1 Role of AD programmes in developing motor competence.

AD programmes are a crucial part of the structured physical development for athletes. They have been presented and developed as an essential factor in the physical, social and psychological aspects of an individual's engagement with physical activities (Lloyd, Faigenbaum, et al., 2014). Pichardo et al. (2018) highlighted three of the main AD models: Developmental Model of Sports Participation (DMSP) (Côté, 1999), the LTAD model (Balyi & Hamilton, 2010), and the Youth Physical Development (YPD) model (Lloyd & Oliver, 2012). These three models, along with others that have been influenced by these, share a common and important factor. They all advocate the establishment of FMS, developing generic coordination and essential physical attributes, before progressing onto more complex skills and training modes (Pichardo et al., 2018). This chronological, or linear, progression from fundamental to complex movement and skill development has its precedent in the previous literature cited earlier (e.g., Lloyd et al., 2016). The motor learning process, as described by Magill (1993) and other indicates that the development and practice of simple movement patterns can evolve into the execution of higher-order skills. While this is established in practice, and AD programmes reflect this progressive approach to motor learning (Gulbin et al., 2013), there is an assumption in most models that this is a unidirectional process through various developmental stages (Starkes, Cullen, & MacMahon, 2004). For example, the DMSP transitions from the sampling years into specialisation years as a defined process, and the LTAD model describes various progressive windows of opportunities (see Section 2.4) in its structure. However, there is no recognition of the potential importance of maintaining a base of generic agility or FMS, the assumption, being that the early and initial development of these fundamental abilities and basic skills is sufficient for their lifelong employment in improving higher skilled movements or complexes. As such, neither performers nor coaches need to revisit in a development plan. It is however assumed that those individuals who are in an AD programme, especially those with a selective element involved, would have a better GMA than those who are in a less structured system, despite the specialisation that occurs.

5.1.2 The importance of motor competence in PL.

The relationship with PL and its role in developing motor competence is important to recognise. A sensible vehicle for this undertaking is the framework offered by PL, not only promoting the actual movement competence of individuals but their perceived competence in undertaking physical tasks. Edwards et al. (2018) stated that "it is proposed that physical literacy influence important health outcomes, such as cardiovascular fitness, strength, motor skills, and obesity status, and it is associated with a wide array of behavioural, psychological, social, and physical variables" (p. 660). Similarly, Lundvall (2015) described PL as developing a conceptual understanding to enable an individual to become spatial and temporally aware of their environment; capable of employing FMS as *building blocks* for complex skills (Favazza et al., 2013). Okely, Booth, and Chey (2004) also suggested that those children that possessed better FMS were more likely to be physically active. As previously discussed (see Section 2.4.2) the concept of PL, in the majority of various conceptualisations, emphasises early developmental training phases which are focused on motor competence and establishing FMS (O' Brien et al., 2016). Notably, however, the extent to which PL is important to AD models is less well researched (Ford et al., 2011). Acknowledging the significance of the foundational and functional development of basic motor skills in children and youths to promote active, and physically able individuals in performance programmes is important (Pichardo et al., 2018). Although the focus in this thesis is on sports performance and focussed on the physiological aspects of PL, the need to recognise the importance of permanent or long-term physical development and physical activity should not be understated (Abbott et al., 2007). However, maintaining generic agility or creating a base of FMS has been shown to influence perceived and actual physical competence in children and youths (Lubans et al., 2010). Indeed, Robinson et al. (2015) stated that “a positive relationship exists between motor competence and physical activity across childhood” (p. 1273). The consequence of this focus on providing fundamental motor competence, therefore directly relates to future engagement in PA and the positive health and wellbeing factors associated with such developments (Stodden, Langendorfer, & Roberton, 2009). Accordingly, it is suggested that assessing GMA is a functional way in which this generic agility or motor competence can be evaluated to help guide physical development and support on-going engagement in physical activity (Edwards et al., 2018). Therefore, as a holistic entity in a role of promoting motor competence (Hands et al., 2018), PL may play an essential part in the ongoing maintenance of FMS and subsequently, to influencing GMA.

5.1.3 The role of PE in developing motor competence.

The relationship between the broader conceptualisation of PL and PE has been previously established, with both areas being closely aligned (Lundvall, 2015). Contemporary PE has begun to take a holistic view of an individual’s development, including creative thinking, problem-solving and decision-making, developing the ability to communicate, promoting empathy and willingness to accept a challenge. McLennan and Thompson (2015) stated: "regular participation in quality physical education and other forms of physical activity can improve a child’s attention span, enhance their cognitive control and speed up their cognitive processing” (p. 6). Overall, these findings suggesting that quality PE develops an individual’s confidence and cognitive abilities, amongst other psychosocial factors, which in due course influence the personal and social aspects of an individual's character. The broader impact of this may well influence the nature of the individual in their sporting realm and the society which they engage in, promoting citizenship and communities in all endeavours. Surely such an impact on an individual is a defining factor of education.

More pertinently to the development of motor competence, PE should develop FMS to support the physical, as well as social traits in an individual, with the specific outcome of improving PL and creating the confidence of these individuals to engage in physical activity for life (McLennan & Thompson, 2015). This may be interpreted as *have-a-go-ness* or determination, in this physical arena (Collins & MacNamara, 2017). Graf et al. (2005), who undertook a school-based intervention which involved combining health education and physical activity, demonstrated positive impacts on motor skills thereby influencing physical inactivity, health indicators and social factors in primary school children. This evidence highlights the positive impact of developing FMS and the impact this can have on PE and lifestyle. This FMS focus is particularly crucial in light of how modern life has impacted PE. Whitehead (2013) summarised this concern by stating that

- "fewer people are continuing with physical activity after leaving school
- sedentary leisure pursuits are on the rise
- cases of obesity and stress-related conditions are increasing
- in many schools and other physical activity settings, there was, and is, a subtle move towards high-level performance being the principal focus of the subject" (p. 22)

Therefore, the role that PE has in establishing and maintaining FMS, operationalised through generic agility, may form a vital part in improving sporting performance, This is highlighted by Malina, (2014), who described children who have difficulty undertaking more complex movement tasks due to a deficiency in FMS. Improving sporting performance and balancing the development of movement confidence in promoting lifelong physical activity (Capistrano et al., 2016), remains an important aspect of PE. It is sensible to note that the education side of PE should be as important as the physical side. Not only should we exercise our young people, but we should be building skill competence as well as building their emotional competence.

Whereas at higher levels of performance we need to be identifying and developing the style of the literacy (*grammar*) of movements to facilitate better performance. Not just that the elements (*words*) and movement literacy (*sentences*) exist, but how they are connected. To reiterate, this is regardless of whether the aim is for elite performance in sport or more recreational activity. Whichever route, there is a place for this PE in skilled movement and performance. This integration should still be one of the primary goals of physical education. Despite this, there has been a shift in some curricula to centre on health-related exercise. This recent focus on increasing PA to try and combat the obesity issue in children and youth in schools has undoubtedly influenced physical education over recent times. This perhaps has impacted the essential base required for more complex skill development, while merely promoting a short-term increase in PA for weight control.

5.1.4 Training to develop GMA.

Structured training programmes are an essential and productive element of AD models to ensure that specific physical adaptations are achieved. Examining how the operationalisation of generic agility, or developing FMS, might be achieved or influenced through such a programme is essential. Periodised training programmes for physical, tactical and skill components are a common and usual aspect of such contemporary programmes (Turner, 2011). That is, the increasing specialisation of targeted physical, tactical and skill adaptations over longitudinal periods of time through subsequent stages of the AD programme is standard practice. These types of structured training programmes have previously been shown to be successful in a variety of training modalities, particularly physical development. For example, resistance training (Jullien et al., 2008; Suchomel, Comfort, & Lake, 2017); speed and plyometric training (Booth & Orr, 2016; Heang, Hœ, Quin, & Yin, 2012; Lloyd, Oliver, Hughes, & Williams, 2012); aerobic and anaerobic conditioning (Turner & Stewart, 2013); coordination (Hopper et al., 2017); CoD (Milanović, Sporiš, Trajković, James, & Samija, 2013); flexibility and balance. They have also been successful in developing different target groups, for example, resistance training in youths (Faigenbaum, Lloyd, MacDonald, & Myer, 2016; Lloyd, Faigenbaum, et al., 2014b). While this progressive development has been acknowledged and reported as necessary for improving context-specific performance (Čoh et al., 2018; Kutlu, Yapıcı, Yoncalık, & Çelik, 2012; Zemková & Hamar, 2018), the impact of incorporating non-specific practice, and the ongoing maintenance of generic agility, is less researched. Specific practice alongside generic agility training, speculatively, could be a potent combination, especially in enhancing athlete robustness and their ability to learn and re-learn motor skills.

Generic agility (cf. Chapter Two) underpinned by a range of well-developed sub-capacities, can be conceptualised from a training perspective as engaging in activities and exercises that develop physical and motor qualities to promote competence and control in fundamental movement patterns, or FMS. These exercises and activities try to ensure that variation and diversification of movement challenges are incorporated in training. In other words, the scenarios, contexts, and environments in which basic movements are practised are varied and diverse, and the quality of movement is maintained. Also, the physical attributes that are employed in these FMS are challenged through appropriate loading of intensity and volume. Generic training may be interpreted as a being aligned to neuromuscular training (NMT), where FMS is combined with various resistance and plyometric programmes to enhance and develop the neuromuscular control alongside fundamental physical attributes (Hopper et al., 2017; Myer, Ford, Palumbo, & Hewett, 2005; Naclerio & Faigenbaum, 2011). NMT programmes are designed and implemented to "improve muscle strength and fundamental motor skill performance by performing a variety of exercises with progressive loads that are consistent with individual needs, goals, and abilities”

(Naclerio & Faigenbaum, 2011, p. 54).

The role of CoD

Given how often it has featured in recent conceptualisations of agility (cf. Chapter 2), the role and relative importance of CoD also merits consideration. For example, CoD drills can be utilised as an NMT (Loturco et al., 2018), developing FMS, speed, and strength. This type of training is a means of developing and enhancing generic agility and therefore impacting GMA. A study by Polman et al. (2004) concluded that training focused upon speed and agility was more effective in the conditioning of female football players. They highlighted that agility type training was effective throughout a training session, and there wasn’t a need for particularly specialised equipment. These findings suggest that generic agility, as a training modality, can influence specific playing performance. In a similar fashion, Bloomfield, Polman, O’Donoghue, and McNaughton (2007) found that general agility training, in the form of speed agility and quickness training, was superior to no training and small sided conditioning games when compared on measures of acceleration, deceleration and agility, although this agility test was on preplanned performance only. Young and Farrow (2013), also highlighted the importance of training the perceptual and cognitive element of agility. They proposed that evasion drills and small sided games offered effective agility training modalities, which help to develop sport specific perceptual and decision-making skills. However, preplanned CoD drills did not enhance cognitive elements of agility but did allow for novice performers to establish their CoD mechanics. Chaalali et al. (2016) studied the training effect of CoD and agility training in youth elite footballers comparing some performance measures. These included linear sprints; CoD runs with and without a ball, 5-0-5 test, and reactive agility test with and without the ball. The training included some CoD tasks involving single and multiple changes of direction, either with or without a ball and under preplanned or reactive conditions. They concluded that the agility trained group improved most on the reactive agility test (with and without the ball), whereas the COD group improved most on the preplanned agility movements and linear sprints. Accordingly, some studies have shown the specific adaptations of CoD and reactive agility performance, as a consequence of related training, but there is a lack of research which has examined the possible connection between GMA and various interpretations of agility. Barnett et al. (2016) stated that

> "While recent papers and systematic reviews indicate interventions can improve gross motor competence in both children and adolescents, published manuscripts lack important details (such as intervention intensity, duration, fidelity and characteristics of facilitators and participants). It remains unclear from these studies which correlate should be targeted to ensure interventions are optimized, and whether or not, and for whom, targeted and tailored interventions should be developed" (p. 1664).

Therefore, there remains an interest in how GMA may develop longitudinally and what specific factors may influence this. For example, how enduring motor abilities, such as generic agility, are developed, when they are considered more general rather than specific?

Growth and maturation.

The impact of maturation on children, and particularly youths, when planning their physical development can be significant, with specific AD programmes having been developed to accommodate this natural process (Lloyd & Oliver, 2012). Read, Oliver, Myer, De Ste Croix, & Lloyd (2018) stated that maturation could cause significant changes in weight and height which can impact movement quality, through disturbances in motor control that may lead to potential increased injury risk. Regardless of an increase in adolescent awkwardness, growth and maturation alone have been shown to affect children's physical and motor abilities. In the absence of any intervention or structured training programme (Malina, 2014; Sherar, Baxter-Jones, Faulkner, & Russell, 2007), performance measures, such as fat free mass and strength, have been shown to improve when growth spurts occur.

5.1.5 Study aims.

Building from these different perspectives, this study aimed to compare and contrast the longitudinal change in GMA within two distinct groups, a school group and a group from a structured RL AD programme (scholarship group), testing for changes in GMA plus differences in preplanned (generic agility) and reactive CoD (specific agility). Using the WMAT, both groups were assessed pre and post a period of intervention and growth. Concurrently, tests of generic agility (preplanned CoD) and specific agility (reactive CoD) were also administered. Reflecting the ideas presented in Section 5.1, it was hypothesised that (a) there would be a significant difference between the GMA of the scholarship and school group, as measured by the WMAT and (b) and there would be a significant improvement in both groups' GMA after the intervention. With regard to the CoD tasks, I hypothesised that (a) the scholarship group would perform better on both preplanned and reactive CoD than the school group, (b) both groups would show significant improvements on the CoD tasks, (c) the scholarship group would show significantly larger improvements than the school group and these improvements would be greater on the reactive CoD than the preplanned CoD task.

5.2 Method

5.2.1 Participants.

The sample consisted of 36 male participants (mean ± SD; age: 16 ± 1 years; body mass: 79 ± 14 kg; height: 174 ± 6 cm), who were physically active youths. This sample was made up of two sub-groups: 21 Junior RL players ($G_{scholarship}$) from a professional club, and 15 children (G_{school}) of similar age and educational stage from a local secondary school. All participants were year 11 pupils. Using inclusion criteria participants were deemed suitable to take part in the study if they were (a) free of significant injury for a period of three months prior to the commencement of the study, (b) physically active through engaging in a minimum of 150min of high intensity activity over a week, and (c) familiar with agility type movements. Before testing each participant was required to attend one familiarisation session, where the testing protocols were explained and rehearsed. The participants read the description of the aim and objectives, risks, and basic procedures of the study and a Physical Activity Readiness Questionnaire was completed. Informed consent was gained from the parents/guardians of all participants. Ethical approval was provided by the School of Sports ethics committee at York St John University, and also by the Business, Arts, Humanities and Social Science ethics committee at the University of Central Lancashire.

5.2.2. Instrumentation.

This research design was a longitudinal controlled trial where participants undertook the WMAT (Campbell & Tucker, 1967), and series of preplanned CoD (CoD_{pp}) and specific CoD (CoD_r) tasks each involving a single 45° change of direction movement, pre and post an intervention programme or a PE curriculum. The different pre and post relationship between the performers' CoD times and their GMA score, using a field-based agility measure, was explored.

CoD tasks and WMAT

The CoD_{pp}, CoD_r and WMAT are the same as described in Chapter Four. Therefore, please refer to Section 4.2.2 for the details of the CoD task and WMAT, also see Appendix B for WMAT protocols.

Intervention and PE curriculum.

The $G_{scholarship}$, who were part of a formal AD programme, participated in an intervention that incorporated a training programme focussed on developing GMA, as well as rugby specific training. This training programme consisted of three 2hr training sessions (Monday, Wednesday, and Saturday). The $G_{scholarship}$ training programme was specific and included structured sessions to train FMS and generic agility. The G_{school} took part in formal curriculum PE sessions during school hours, and this consisted of two 1 hr session of PE classes per week. This G_{school} was considered a general PA programme deigned to fulfil a PE curriculum at key stage four. No assessment of maturation was undertaken during the study. The detail of the $G_{scholarship}$ intervention programme and the G_{school} PE curriculum can found in Table 5.1. Specific examples of a mesocycle, a microcycle or session content can be found in Appendix C.

Table 5.1.

Overview of the $G_{scholarship}$ intervention programme and the G_{school} PE curriculum.

Group	**Session 1**	**Session 2**	**Session 3**
$G_{scholarship}$	Gym based session: FMS training, strength, power & muscular endurance resistance exercises	Field-based session: Metabolic conditioning, FMS training, acceleration, and deceleration drills, preplanned and reactive CoD drills. RL skill development	Field-based session: Metabolic conditioning, FMS training, acceleration, and deceleration drills, preplanned and reactive CoD drills.
G_{school}	Sports hall based session: Introduction to sports skills (various)	Field-based session: Introduction to sports skills (various)	

5.2.2. Protocol.

Each testing session began with a standardised 10-minute dynamic warm-up, including running, bounding and dynamic stretching, followed by the respective testing protocol. Participants completed three CoD_{pp} trials and six CoD_r, three trials for both right and left directions, with the order randomised throughout testing. The best trial, based on PT, from each CoD task, was used for further analysis. Testing took place over two sessions separated by a seven-day period, thus ensuring that adequate rest was allowed between the WMAT and both CoD tasks. Testing was carried out at the beginning of preseason and once again six months later. The testing sessions were carried out at the same facilities each time and under similar conditions. All testing took place on an outdoor 3G surface, with participants wearing rugby boots, except the alternate handball toss which took place indoors.

5.2.3 Data analysis.

Statistical analyses were performed with SPSS Version 24 (IBM Corporation, Armonk, New York, USA). Individual WMAT scores were processed as in Chapter Three (see Section 3.2.4). Preliminary analyses for normality (Kolmogorov-Smirnov), homoscedasticity and equality of variance (Levene's test) were performed. To examine the interaction between groups (Scholarship and School) and time (pre and post) in WMAT, CoD_{pp} PT and CoD_r PT variables, three mixed method 2 x 2 (Group by Time) ANOVAs, with repeated measures on the second factor were used. ES was also calculated for each test using the *F*-ratios, and these were interpreted according to the values suggested by Cohen (1992) where 0.1 = small, 0.3 = moderate and 0.5 ≥ large when assessing an *F* value. statistical significance of 95% was used ($p < .05$).

5.3 RESULTS

5.3.1 Data characteristics.

All data were normally distributed, and homoscedastic, sphericity and equality of variance was assumed.

5.3.2 Intervention programme and PE curriculum effects.

There was a significant effect of time on WMAT, $F(1,34) = 93.25$, $p < .01$, with a very large ES (.73). While the group effect, dependant on whether participants were in the $G_{scholarship}$ or G_{school} was also significant at $F(1, 34) = 5.70$, $p < .05$, though the ES was small. However, there was no significant interaction between time and group when considering WMAT scores (see Table 5.2). On average participants from the $G_{scholarship}$ had significantly larger WMAT scores than the G_{school} at the start (scholarship mean = 59.23, SD = 12.45, school mean = 49.92, SD = 9.95) and finish (scholarship mean = 67.20, SD = 10.09, school mean = 58.83, SD = 12.33) of the intervention or PE curriculum. This meant that for both groups there was an increase in WMAT score ($G_{scholarship}$ mean difference = 7.98, SD = 4.12, G_{school} mean difference = 8.92, SD = 6.39).

The effect of time on CoD_{pp} performance was significant, $F(1,34) = 32.52$, , $p < .01$, with a moderate ES; though the group effect for planned CoD task was not significant (see Table 5.2). There was, importantly, a significant interaction between time and group when considering CoD_{pp} performance, $F(1,34) = 7.89$, $p < .001$; this had a small ES ($r = .19$). The mean PT for the $G_{scholarship}$ showed a small difference with that of the G_{school} in the pre testing, although there was a large difference in the post testing. This demonstrates that there was a significant decrease in CoD_{pp} PT (scholarship mean difference = -0.13s, SD = 0.11, school mean difference = -0.05s, SD = 0.06) for both groups.

Finally, when examining CoD_r performances, time again was a significant factor, $F(1,34) = 18.77$, $p < .001$. The ES was moderate ($r = .36$). There was also a significant effect of group on PT, $F(1,34) = 5.72$, , $p < .05$ with a small ES ($r = .14$). Though again there was no significant interaction between group and time. CoD_r times were, on average, faster in the $G_{scholarship}$ than the G_{school} pre and post testing, for both groups there was a significant decrease in CoD_r PT ($G_{scholarship}$ mean difference = -0.09s, SD = 0.14, G_{school} mean difference = -0.09s, SD = 0.09).

5.4 Discussion

This study aimed to identify the effect of a six-month training period on GMA, generic and specific agility performance, contrasting these between two groups of participants who were either involved in a specific intervention programme or a general PE curriculum. The findings of this study suggest GMA is a capacity that can improve, regardless of whether there is a structured training programme which is focused on developing and maintaining FMS or generic agility or engaging in general PA programme, including a PE curriculum. It was also clear that GMA performance is representative of the level of athletic development in an individual, and this has an association with performance on more context-specific tasks (see Chapter Four), specifically this relates to WMAT and CoD_r performances. Therefore, a number of the hypotheses of this study can be accepted. Namely, there was a significant improvement in both groups' GMA after the period, as well as there being a significant difference between $G_{scholarship}$ and G_{school} GMA, as measured by the WMAT. It can also be accepted that both groups showed significant improvements on the CoD tasks, and the $G_{scholarship}$ performed better on both preplanned and reactive CoD task than the G_{school}. However, the hypothesis that the scholarship group would show greater improvements than the school group and these improvements would be greater on the reactive CoD than the preplanned CoD task was not supported by the evidence.

Table 5.2.

Descriptive statistics, *F* values and ES

Test	**School**[a]				**Scholarship**[b]				***F* Values (ES)**		
	Pre		Post		Pre		Post		Time	Group	Time*Group
	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI			
WMAT	49.92 (9.95)	44.41, 55.43	58.83 (12.33)	52.06, 65.61	59.23 (12.45)	53.56, 64.89	67.20 (10.09)	62.61,71.80	93.25 (.73)***	5.70 (.14)*	.29 (.01)
CoD_{pp} (s)	2.26 (0.11)	2.19, 2.32	2.21 (0.11)	2.15, 2.27	2.28 (0.15)	2.22, 2.35	2.15 (0.14)	2.09, 2.21	32.52 (.49)***	.15 (.00)	7.89 (.19)***
CoD_{r} (s)	2.35 (0.14)	2.28, 2.43	2.26 (0.12)	2.19, 2.33	2.25 (0.14)	2.18, 2.31	2.16 (0.15)	2.09, 2.23	18.77 (.36)***	5.72 (.14)*	.00 (.00)

Note. SD = standard deviation, CI = confidence intervals
[a] N= 15, [b] N = 21
**p* < .05. **. *p* < .01. ****p* < .001

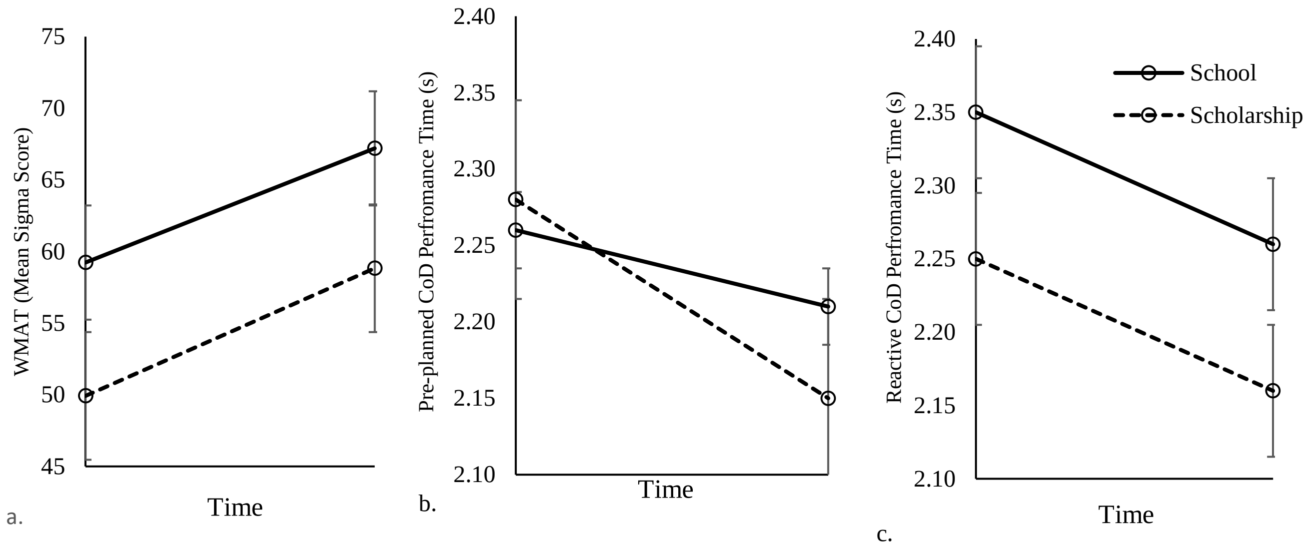

Figure 5.1. Mean change in (a) WMAT (b) CoD_{pp} PT and (c) CoD_r PT.

Table 5.3.

PA of the G_{school} outside of their PE curriculum.

Participant	**Activity**	**Active years**
Participant 1	Football	10
Participant 2	Football & Cricket	11
Participant 3	Football	6
Participant 4	None	0
Participant 5	Football	2
Participant 6	Football & Cricket	10
Participant 7	Football	8
Participant 8	Rugby	10
Participant 9	Football	6
Participant 10	Football	7
Participant 11	Football	3
Participant 12	Football	1
Participant 13	Basketball	2
Participant 13	None	0
Participant 15	None	0

5.4.1 GMA

The significant improvement in both groups' WMAT in pre to post testing ($F(1,34) = 93.25$) demonstrated that GMA is a developmental attribute and not a fixed entity, it can be developed and enhanced, regardless of the specific nature of the training or PA that individuals are engaged in. Hands et al. (2018) described a situation where GMA is in constant flux, changing in response to several factors: personal, developmental, and environmental. Focusing upon these factors, the results here seem to support the concept that GMA can be developed over time, though this is not restricted to specific types of training (Hands et al., (2018). These findings are at odds with Vandorpe et al. (2012) who speculated that motor coordination was relatively stable over a two-year period ($r > 0.72$) in younger children, though the age of the participant group may have influenced their conclusion. The change in GMA may be influenced by (a) the individual concerned, (b) their stage of development, and, (c) the external demands placed upon them in any specific movement challenge. As suggested, the role that PL may play in the ongoing or lifelong development and maintenance of FMS, operationalised through PE (Stodden et al., 2009) or an appropriately structured AD programmes, is significant. This approach of engaging in the continual maintenance of the building blocks of sports-specific skills represents a significant addition to the knowledge of AD and applied practice in utilising the concept of GMA.

Further, the performance on the WMAT was significantly different between two groups ($F(1, 34) = 5.70$), with a difference between groups remaining from the initial testing point on GMA performance to when the groups were retested (see Figure 5.1a). At initial testing, the G_{school} had a mean WMAT score of 49.92 sigma points (SD = 9.94,) and the $G_{scholarship}$ mean 59.23 points (SD = 12.4) with the mean difference of 9.31 sigma points, (SD = 3.88) ES were $G_{scholarship} = 1.25$ and $G_{school} = 1.20$. This initial larger WMAT score in the $G_{scholarship}$ reflects the experience and selective nature of this group over the G_{school}, and is, perhaps, indicative of an appropriate selection (Collins & McNamara, 2018) into a structured AD programme. Vandorpe et al. (2012) observed that higher co-ordination across groups of children was associated with those who consistently engaged in sport, highlighting the benefit of obtaining a higher level of motor coordination in contributing to improved participation in sport. This difference in WMAT between groups may also reflect the ability of a GMA assessment tool to successfully discriminate level of performer, as previously highlighted (Ibrahim et al., 2011; McCloy, 1934). Postintervention the G_{school} had a mean WMAT score of 58.83 sigma points (SD = 12.23) and the $G_{scholarship}$ mean was 67.20 sigma points (SD = 10.09) with a mean difference of 8.37 points (SD = 3.73). This difference in scores indicates the disparity between the two groups and that the relative change in GMA was uniform from the beginning to the end of the intervention (see Figure 5.1a)

The difference between intervention programme and PE curriculum.

The relative WMAT improvements in both G_{school} and $G_{scholarship}$ across time regardless of which training they undertook, indicates that GMA can be developed, and performance can be improved over time. This similarity in GMA improvement is despite the different training both groups participated in, the $G_{scholarship}$ focussing on developing specific gameplay and covering physical, generic and specific improvements for RL, with a particular focus on developing generic agility and FMS, while the G_{school} PE curriculum reflected a broader spectrum of PA but revolving around the PE curriculum for year eleven boys at key stage four (see Appendix D). In this general PA programme the participants were involved in two 1 hr practical sessions which comprised of various introductions to games activities. Although the PE sessions provided general instruction on gameplay to the participants, the main aim was engaging youths in various games activities. The aim of these PE sessions was not to target and develop the physical and technical attributes required to perform at a higher level but provide an introduction to each sport and promote PA (Stodden et al., 2009). In quality PE one of the main aims is to develop psychomotor skills that will support lifelong physical activity. Though the aim here is not to critique the PE curriculum, it should be commented that in this participant group the improvement in GMA can in part be attributed to the activities they engaged in. O'Keeffe et al. (2007) provided evidence to support the findings here that the transfer from developing skills in one environment supports achievement in another. The benefits of general gameplay in the G_{school} from their PE curriculum, supporting their general improvement in the test of GMA. Lundvall (2015) commented that PL as a concept was becoming part of the discussion for physical educators, and to some extent practitioners working in AD; this positive development is reflected in this study, with both interventions demonstrating improvement in GMA.

The $G_{scholarship}$ group were involved in three structured 2 hr sessions during a week, including specific elements of each session dedicated to enhancing their physical, technical and FMS level (see Appendix C). In the strength and conditioning elements of the sessions, there was a particular focus on developing and maintaining generic and specific agility for RL. The gym based sessions followed a structured plan for the development of strength, power and muscular endurance, with a particular focus upon FMS and NMT. These FMS exercises involved generic movement challenges in preplanned, reactionary movements and static and dynamic control, incorporating locomotor manipulation and non-manipulation movements, while the gym based NMT work was designed to develop strength as well as focus on movement quality and technique. The field-based sessions involved generic and specific agility exercises, such as preplanned and reactive, generic and specific agility movements focussing on FMS, speed and movement quality. This type of training may also be interpreted as NMT training (Loturco et al., 2018). As discussed, both groups did improve their

WMAT mean score pre and postintervention; however, the absolute mean score in each group and the corresponding increase over time were different. The initial difference in WMAT score preintervention for the $G_{scholarship}$ is indicative of the selective nature of this group (Tribolet et al., 2018; Vandorpe et al., 2012). However, the absolute difference in WMAT score throughout the intervention programme compared with the G_{school}, confirms the more significant impact on GMA as influenced by the focus on generic agility training (Giles, 2007). Therefore, it is proposed that the specific GMA training undertaken by $G_{scholarship}$ be associated with the significant difference identified between the groups. Speculatively, this could have been defined by different levels of physical attributes in the participants of each group, including the disparity in speed, strength, and power (Jones et al., 2018).

The disposition of the school group to engage in PA.

The change in WMAT over time in the G_{school} is worthy of note, notwithstanding the lack of a significant interaction between time and group in WMAT performance. Despite the lower initial mean sigma score than the $G_{scholarship}$, this group did improve their WMAT performance, regardless of not being in a structured AD programme. This improvement confirms that GMA is a changeable entity, and is influenced by the involvement of physical activity; whether this is through general PA, the PE curriculum (Chen et al., 2017), or potentially by growth maturational development alone. This physical maturation has previously been shown to influence physical ability and skill (Lloyd, Oliver, Faigenbaum, Myer, & De Ste Croix, 2014; Pichardo et al., 2018). In a more exploratory manner, it should be noted that the G_{school} were asked as to their PA outside of the PE curriculum (see Table 5.3). A number of the G_{school} were involved in other physical activities, playing a recreational sport for many years, although none were in a structured AD programme. It is clear that the combination of their PE sessions, the non-curriculum PA, and elements of growth and maturation did have a bearing on their GMA, and the subsequent increase in WMAT performance for G_{school}.

To summarise, GMA, as measured by WMAT, changed over time in both groups. The findings in this study therefore indicate that GMA is not an enduring feature of an individual, but liable to development. This change can seemingly be influenced by numerous factors, including participation in structured AD programme (e.g., Lloyd et al., 2016), engagement in a PE curriculum, general physical activities (cf. MacNamara et al., 2015) or maturational changes. The suggestion that improving and maintaining GMA over time is therefore deemed important (Lubans et al., 2010), that rehearsal and practice of generic agility would support the continued development of sub capacities that are reported to influence GMA (Liefeith et al., 2018). Therefore, programmes of lifelong athletic development and programmes of general physical activity should consider incorporating elements of this generic agility type training, for all level of performers and at all stages of development (Stodden et al., 2009). Also, participants who are selected onto a structured AD programme, based on their potential of athletic giftedness, are significantly different to participants who are not part of such a programme, i.e., programmes with a generic agility focus based upon their WMAT performance. This difference indicates that the underlying abilities or sub capacities (see Section 2.3.1) which support GMA, benefit from continued training regardless to the nature of intervention engaged in, but mainly because these capacities are liable to changes over time. As such, this indicates the potential of a GMA assessment to discriminate athletic giftedness (see Section 3.1.3). It should, however, be noted that future investigations looking into the structure and content of training intervention for the development of GMA, should be encouraged.

5.4.2 Change of Direction

In Chapter Four the significant relationships between GMA and CoD_{pp} and CoD_r were presented and discussed, demonstrating that GMA can predict performance on these generic and specific agility movements. In this study, both groups showed a significant improvements on the CoD tasks, in CoD_{pp} performance time ($F(1,34) = 32.52$, $p < .001$) and CoD_r performance ($F(1,34) = 18.77$, $p = < .00$). Firstly, for CoD_{pp} performance time, Figure 5.1b demonstrates that though the mean performance time was lower in the G_{school} (mean = 2.26s, SD = .11) than the $G_{scholarship}$ (mean = 2.28s, SD = .15) at the start of the intervention. However, at post-testing, the $G_{scholarship}$ were significantly faster than the G_{school}. ES were $G_{scholarship}$ = .63 and G_{school} = .21. Both groups had decreased their overall CoD_{pp} performance time, with a mean difference of 0.06s (SE = 0.04). Similarly, CoD_r performance times were significantly different pre and postintervention, reducing by 0.09s. Specifically, in CoD_r, the $G_{scholarship}$ (mean = 2.25s, SD = 0.14) being significantly faster than the G_{school} (mean = 2.35s, SD = 0.14) at the initial testing phase. At post testing, the difference between the groups remained significant, $G_{scholarship}$ (mean = 2.16s, SD = 0.15) being faster than the G_{school} (mean = 2.26s, SD = 0.12) in CoD_r. ES were $G_{scholarship}$ = .54 and G_{school} = .47 . These significant improvements in CoD_{pp} and CoD_r regardless of group, reflect the findings from Chapter Four, where better GMA coincides with better general and specific CoD performance. These findings reflect the potential benefits of developing and maintaining good GMA, whether this is through a targeted specific programme of generic agility and FMS training or engaging in general PA programme with a PE curriculum, to affect general and specific CoD performance. Speculatively, this may be interpreted as an improvement in GMA, operationalised through generic agility training, supporting performance in specific agility outcomes (Liefeith et al., 2018). This operationalisation of generic and specific agility supports the use of GMA as a representation of overall athleticism, which may help guide the identification of giftedness. In particular, it may also represent the ability of an athlete to apply general movement qualities to produce solutions in more sport or context specific situations. A significant interaction between time and group ($F(1,34) = 7.89$, $p < .00$) for CoD_{pp} perhaps highlights the influence of the specific training programme of the Gscholarship to improve CoDpp performance time, as previously emphasised by Simonek et al. (2016) when comparing reactive and pre-planned agility tasks. While the ES ($r = .19$) was small, this illustrates the influence of training type and the level of the performer on non-reactive CoD performance or generic agility and is reflected in the difference in the level of GMA of these two groups.

The accepted hypothesis that the $G_{scholarship}$ would perform better on both preplanned and reactive CoD task than the G_{school} was confirmed by the differences in CoD_r performance. Green et al. (2011b) used a similar protocol to that employed in this study, using a 45° cut. In their study, the best mean CoD_{pp} time was 2.09 s and in the reactive version, the best mean time was 2.34 s. Therefore, they found there was an 11.96% differential between preplanned and reactive CoD task. Though the distance of the CoD protocol in this current study was approximately 1.3 m longer, performance time was seemingly equivalent. From an exploratory perspective, the differentials between Cod_{pp} and Cod_r were somewhat smaller across both groups and across time (G_{school} pre = 3.98% & post = 2.26%; $G_{scholarship}$ pre = -1.32% & post = 0.47%). Interestingly, the $G_{scholarship}$ had both a negative and negligible differential between Cod_{pp} and Cod_r performances. This smaller difference may reflect the higher standard of the $G_{scholarship}$ to perform sport-specific movements and highlight the nature of the specific training they undertook as being influential in developing specific agility. Though the nature of this relationship has been described before, Wheeler and Sayers (2010) commented that the difference in pre-planned and reactive agility performance does not reflect level of performer, despite recognising the importance of reading cue from a *live* stimulus in reactive performances

The final hypothesis was rejected, as the $G_{scholarship}$ did show significant improvements, more than the G_{school} in the CoD_{pp}, but relatively similar improvements in the CoD_r, this was unexpected. Although the $G_{scholarship}$ had significantly faster times in the CoD_r than the G_{school} the improvements in performance times pre an postintervention was consistent in both groups. This consistency is despite the disproportionate increase in CoD_{pp} performance time in the $G_{scholarship}$. As discussed earlier, the improvements in the CoD_{pp} in $G_{scholarship}$ is suggestive that the specific intervention impacted their CoD ability more than a general programme. However, the G_{school} relative improvement in CoD_r reflects the slow performance time preintervention and the impact of their general programme on WMAT and CoD_r in improving performance.

Though these improvements in WMAT and CoD performance may be as a consequence of generic agility, it is apparent that this could be in part due to growth and maturation across the intervention period (Malina, 2014). Interestingly, Barros et al. (2017) suggested that motor capacities, such as strength, agility, balance, and flexibility, are not influenced by maturational advancement in adolescents. As such the issue as to whether or not any growth and individual's maturation influenced the results of this study cannot be either discounted nor confirmed.

To summarise this section, the significant interaction in group and time for CoD_{pp}, and the significant difference between the groups postintervention may suggest that the focus on generic agility influenced the different change in CoD_{pp} performance across groups. The employment of generic agility training, utilising FMS and NMT, in the $G_{scholarship}$, seemingly explains the disproportionate change in CoD_{pp}. While the relative difference in CoD_r is similar in both groups, the absolute difference is significant pre and postintervention.

Some limitation in the scope and design of this study may have influenced the outcomes and should be noted. They include lack of an account of participant maturation and the relatively small sample size. Maturation was not accounted for in this study; it has previously been shown that changes in performance of youth athletes are linked to their chronological age and maturation state (Lloyd et al., 2016). Vandorpe et al. also highlighted the test-re-test effect in assessments of motor coordination, stating "the relative increase in motor quotient (MQ) values of all groups, independent of the level of sports participation over time, could be attributed to a systematic practice effect caused by repeated measuring" (p. 223). However, the impact of the learning effect on WMAT and generic and specific agility assessments in this study was deemed small, based upon the relative simplicity of the assessments.

5. 4.3 Practical application.

The practical application of the finding of this research suggests that practitioners should consider incorporating the development and maintenance of generic agility to support specialisation, skill transfer and influence athlete robustness, through employing and encouraging movement variation and diversification to support specificity. Practically, this means incorporating reactivity, variety and challenge into exercises and drills to encourage the creation of a novel solution to preplanned and reactive movements. These may be rehearsed via FMS training, through NMT, to benefit movement control, coordination and execution. Kiely (2017) highlighted that "what emerging scientific insight does add, however, is a growing appreciation of the value of regularly challenging running coordination through the design and implementation of appropriately constructed practices" (p. 8). Providing a recurring focus on controlling movement variation and increasing diversification in all levels of athletes is a key message. Three training themes emerge when considering the selection of exercises to incorporate locomotor, manipulation and non-manipulation movements and therefore target specific attributes to develop (speed, forceful contraction, mobility, dexterity, balance, postural control, coordination, perceptual awareness, reflexive decision making). These themes have been broadly described as:

- Movement control and kinaesthetic awareness. Where fundamental movements are performed with precision and reliability. There may be a focus on working across a full range of movement. A range of movements speeds would be included. This theme incorporates functional skills such as static and dynamic balance and postural control.
- Movement coordination and dynamic movement control. The coordination and control in more multiplanar dynamic movements. Incorporating a wide range of diverse movement patterns emphasising dynamic drive and plyometric action, e.g., landing and take-off mechanics. These would involve problem-solving challenges. Gross locomotor skills, such as running jumping, skipping and manipulative skills such as throwing and catching are utilised in this theme.
- Movement power and reactivity. Movements that involve appropriate control and delivery of power. Plyometric exercises and dynamic power movements are targeted in this theme.

Including general movement skills or FMS in an AD programme during a mesocycle is seemingly essential. Whether it be in a warm-up, dynamic stretching, movement challenges or agility drills, all these incorporate opportunities to focus upon FMS or generic agility. From a practitioner's viewpoint these occasions, in a time-pressured developmental environment, are an example of an ideal opportunity to focus upon the quality of movement in diverse activities.

5.4.4 Chapter Summary.

These findings demonstrate that the level of performer defines GMA level, and regardless of this status, GMA does change over time (Hands et al., 2018). This change in GMA may have implication for long-term or lifelong activity, and it is suggested that maintaining the *health* of an individual's generic agility to support specific movement patterns is a vital element that should be incorporated in AD programmes. What is being proposed in this study is regular and planned training interventions that ensure that the *health* of generic agility capabilities is maintained, to serve better the specific agility challenges which will be encountered and are necessary for sports performance. This *health* of generic agility could be assessed by utilising a simple GMA assessment tool, to represent the status of generic agility. This same GMA could also be an indicator of athletic potential, the findings here have shown the WMAT can discriminate levels of performers. Practically, AD programmes should consider incorporating generic agility training on a regular basis, involving a focus on FMS in various and diverse scenarios.

Building on the review in Chapter Two (e.g., Liefeith et al., 2018) I speculated that GMA might facilitate skill transfer in sport-specific movements and offer a degree of protection against injury to athletes. Contrary to previous research (Haugen, Tønnessen, Hisdal, & Seiler, 2014) it is suggested in this thesis that possessing good levels of GMA enables the transfer of skill in active participants to specific sports skills, this is a novel area of research. Accordingly, Chapter Six summarises an investigation which examined the influence of an individual's level of GMA on their ability to adapt to a novel challenge. This adaptability and potential skill transferability may benefit an individual in learning and re-learning skills, promoting neuromuscular resilience and reducing the risk of injury.

Chapter Six

Does it Have an Impact? The Impact of GMA on Novel Task Performance and Evolution

6.1 Introduction

In this chapter, my aim was to examine the impact of GMA on the performance of a complex and novel task. I examined the hypothesis that possessing an established and broad range of FMS facilitates transfer and success in attempting new and novel movement challenges. Individually, a group of participants were ranked on their GMA, and they were also repeatedly measured on their performance of a novel task that involved linear acceleration and deceleration, CoD and a reactive element in some complex manner. It was postulated that individuals with better GMA would improve their performance on the novel task more than the individuals with lower GMA. This would highlight the potential importance of good GMA being a precursor to effective motor learning and skill transfer (Clark & Metcalfe, 2002), through the development of various physical attributes, FMS, and cognitive abilities, that underpins skilled performance (Barnett et al., 2016) and injury resilience or athlete robustness (Paszkewicz, Webb, Waters, Welch McCarty, & Van Lunen, 2012).

The ability to learn motor skills is an integral aspect of sports performance, as is the ability to continue to develop and refine skills for a broad spectrum of specific movement outcomes (Magill, 2001; Schmidt & Lee, 2014). These specific outcomes may manifest themselves as specialised techniques or combined skills to construct tactical and technical strategies. These are both defining factors in attaining sporting expertise and excellence (Baker & Horton, 2004; Baker, Horton, et al., 2003), and also for continued engagement in PA and maintaining good health (Ali, Pigou, Clarke, & McLachlan, 2017). Therefore, understanding the process of developing motor skills, underpinned by appropriate neuromuscular abilities, is essential in developing athletic performance. As a consequence of typical features in this developmental process (e.g., the occurrence of injury, requirement to learn new skills or to enhance the status and already established skills (Carson & Collins, 2015), re-learn previous skills, or transfer skills) the ability of an individual to rely and capitalise on their motor competence and coordination, is essential. Due to possessing good GMA it is suggested that these individuals can capitalise on their broad movement experiences to fulfil the requirement of the new task. It is proposed that an adaptive system which includes the ability to employ an array of general motor competencies, would prosper in these motorically challenging situations.

The extent to which an individual can transfer underlying physical or motor skills to novel or new skill-based tasks remains unclear and therefore warrants further investigation, as there is uncertainty about the extent and underlying mechanism which may facilitate the transfer and benefits received from such a proposal (Issurin, 2013). This potential of transfer is especially pertinent considering the contemporary focus on the importance of specificity of training and development (Young, 2006), where the identified narrowing of the general motor competence base is unidirectional and extremely progressive (see Section 2.4.2). In order to understand the relationship that GMA may have with the learning of a novel task it is useful to review the process of learning and developing motor skills.

6.1.1 Learning motor skills.

Perceptual, cognitive and motor skills are essential human qualities which influence performance in many domains, particularly in locomotion. Motor skills development is vital to support engagement in PA (Lubans et al., 2010b) and particularly important in improving sports performance (Pichardo et al., 2018). Learning motor skills is a crucial aspect of gaining competence in complex sports techniques, and it is therefore a significant part of teaching and coaching in sport. Diedrichsen and Kornysheva (2015) stated “Learning motor skills evolves from the effortful selection of single movement elements to their combined fast and accurate production" (p. 1). The improvement in a motor skill may come from several areas, such as the cognitive aspect of choice and decision making or muscle command and activation. Motor skill can be simple or complex, Wulf and Shea (2002) defined simple motor skill tasks as having a single degree of freedom, contrived and can quickly be achieved or mastered, whereas complex skills are described as more ecologically valid, involved numerous degrees of freedom, and take some time to succeed in where the performance asymptotes (Newell, Broderick, Deutsch, & Slifkin, 2003). Interestingly, Wulf and Shea suggested that using a simple task with a low number of degrees of freedom or where the information-processing demands are small, creates a situation where transfer to more complex skills does not entirely occur.

Coordination in a multi-segmental model, such as the human body, where there are hundreds of muscles producing actions across multiple joints is very complex. Original work by Bernstein (1967) in coordination helped develop the degrees of freedom solution, where control over these vast arrays of movement solutions offered a model of enabling development of motor control, through redundancy degrees of freedom. Diedrichsen and Kornysheva (2015) suggested there is a distinction in defining motor skills and motor adaptations, these motor adaptations are seen to be the practising and improvement in motor techniques, improving the technical efficiency of such movements, as opposed to motor skills which are developed through improvement in the speed and precision in novel movements. Therefore motor adaptation or techniques might be established initially followed by the refinement in operationalising them to produce a motor skill. A critical aspect of establishing good motor skills is reliant upon essential FMS. An individual's level of coordination, motor ability or competence and their FMS affect the ability to learn and develop new or more complex skills, especially in children and youths (Stodden et al., 2008). As children grow their coordination improves and they begin to develop FMS. However, this learning process is not solely based on time or growth (Chen et al., 2017; MacNamara et al., 2015). Favazza et al. (2013) stated that motor skills depend on the acquisition of skills such as balance, which are well practised, confirming that "possessing sound fundamental motor skills enables the child to move about in a variety of ways with fluidness, efficiency, and ease." (p. 236). The schedule for establishing and the mechanics of delivering FMS has previously been investigated, with the ongoing debate surrounding the interplay between deliberate practice and deliberate play (Berry et al., 2008; Ericsson et al., 1993; Ford et al., 2009). MacNamara et al., (2015) introduced the concept of deliberate preparation; this has been offered as an alternative to deliberate practice and deliberate play, essentially extolling the virtues of structured practice and unstructured play. They suggest the development of FMS should be deliberately planned and rehearsed, to ensure that these foundational motor competencies are firmly established at a younger age; with MacNamara et al. (2015) suggesting that children who have appropriate instruction and practice in a wide variety of movement experiences are provided with "the best chance to become successful movers" (p. 1548). Excellent FMS developed from a wide range of experiences in structured and unstructured environments offers a sound foundation for the development of sport-specific motor skills. Baker et al. (2003) suggested a particular benefit of developing FMS, when transitioning from FMS to more sport-specific performance, is that these FMS "may be transferable across sports and activities that share similar general capacities." (p. 14). In due course, this generic base of FMS supports the achievement of specific movement challenges, which are both sport and context-specific. Once again this highlights that GMA benefits attainment of motor skills and potentially facilitates the transfer or re-learning of skills. This evidence is contrary to the contemporary view on skill transfer (e.g., Ellison et al., 2017) which suggests that pursuing and targeting more sport specific challenges, not only reaps greater rewards but that practising more generic training is unproductive (Phillips et al., 2010).

6.1.2 Mechanisms underpinning motor learning and GMA

The process of learning motor skills has been briefly reviewed and discussed. However the interaction between learning of generic and specific motor skills, and the potential for transfer necessitates examination of the mechanisms underpinning motor skills.

Previously, the longstanding theory of motor learning, that of creating and refining motor programmes (Schmidt, 1975), looked to reduce neural and muscular variability in motor skills. For example, decreasing reaction time, through the requirement for less motor planning or preparation time in producing a movement outcome. This improvement in motor performance was due to the ability of the system to create a plan of action which could be initiated on request, for any movement outcome. Motor programming has long been associated with specificity in motor learning, with modification of programmes for each context-specific task. As a counterpoint to motor programmes, dynamics system theory (DST) has become established as a significant theoretical concept to support the various aspects of skill development. DST focusses on increasing redundancy in degrees of freedom to improve motor competency and skill movement. With regards, specifically, to motor learning DST allows for the integration of multiple areas of influence in the production of coordinative movement solutions. Conceptually, this approach allows for several interacting parts, to self-organise, through a constant change between components (Davids, Lees, & Burwitz, 2000). Rather than fine-tuning motor programmes, through the dynamic interaction of competing and cooperative components of a system, movement solutions are said to emerge (Phillips et al., 2010). By controlling the degrees of freedom, DST offers an increase in efficiency of motor control and coordination. However, Davids et al. (2000) did state that “the significance of this approach is that there is now much more importance attached to the specificity of task constraints and individual variability in achieving task outcomes" (p.711), highlighting that even in this dynamic approach the importance attached to specificity of movement outcomes.

More recently the concept of degeneracy has been applied to the dynamic development of coordination and motor skill. Edelman and Gally (2001) described neurobiological degeneracy as “the ability of elements that are structurally different to perform the same function or yield the same output” (p. 13763), therefore allowing coordination to be achieved with a high degree of adaptability within a system when changes in setting and requirements of an outcome occur. Although degeneracy advocates a multidimensional approach to developing sporting expertise, it can also be interpreted to apply to the development of motor skills. Degeneracy enables the successful outcome in motor performance due to the dynamic integration of neuromuscular components. Kiely (2017) contextualised the concept of degeneracy describing how the ongoing monitoring of sensory information creates adaptable movement solutions. That is, dynamically balancing the requirements of a specified movement outcome, evaluating the available neuromuscular assets and assessing the levels of threat to the system (potential injury) aids this adaptability. Motor modules, consisting of groups of independent muscles or joints, have been suggested as a having a key role in coping with the motor learning in a complex system. Indeed, in the context of a coordinated running technique, Kiely stated that

> “Modularity is a fundamental neuro-biological organizing principle, greatly simplifying otherwise overwhelmingly disordered complexity. Related modules exhibit extensive functional overlap, such that alliances of neural networks and peripheral tissues can spontaneously modify behaviors to achieve equivalent ‘outputs’ through a multiplicity of pathways” (p. 3).

Therefore, this modularity has an essential role in creating coordinated movement patterns and the neural mapping of these various motor modules is important. This neural mapping serves as a control mechanism, and in doing so, offers a degree of resilience in the system. Re-routing and reconfiguring of the network and modules allow flexibility and *sharing of the load* in producing specific movement outcomes with a degree of variability.

The role of neural plasticity to support a dynamic systems approach.

The use of neuromuscular plasticity is vital in promoting and embedding useful signals within a complex neural map . It is pertinent to reiterate the role of plasticity in motor learning and the impact or usefulness of plasticity of the neuromuscular system in sports performance. Kiely (2017) stated, "persistent plastic remodelling customizes networked neural connectivity and biological tissue properties to best fit our unique neural and architectural idiosyncrasies, and personal histories: thus, neural and peripheral tissue plasticity embeds coordination habits" (p. 1) that can lead to compliance with movement solutions and consequently athlete resilience. Therefore, I suggest that robustness can be operationalised by continually challenging the neurological system, as well as the ongoing targeting of underlying physical capacities through generic agility training. Such training produces a well maintained neuromuscular system (Diedrichsen & Kornysheva, 2015) which is adaptive and incorporates a high degree of variability (see Section 4.4.3), thereby building a degree of resilience into the system. Those individuals who can incorporate variability in their sport-specific movement solutions or movement techniques and can call on competent and well-maintained FMS reduce the chance of overtly and repeatedly stressing or overloading specific tissues. Spreading this load across and between a greater range of tissue reduces the chance of *pinch points* of mechanical stress and the potential breakdown of tissue and subsequent injury risk (Kiely, 2017). Although this theoretical proposal was not directly investigated in this thesis, it is worthy of future research as an area of interest in injury prevention. For example, how incorporating the deliberate preparation of generic agility training may increase the functional longevity of athletes in AD programmes and reduce injury rates.

In summary, the importance of GMA, physical movement skills or competence in FMS as a foundation to underpin complex skill and long-term PA development (Giblin et al., 2014), may link to these conceptual views on the integrative and dynamic approach to motor learning. Speculatively, GMA in individuals may represent the motor ability of these motor modules, which are dynamically employed in specific movement outcomes. More pertinently, it may also help explain the proposed relationship in the transfer of generality to sports or context-specific movements. Of importance is the consequence of this dynamic fluidity in a motor module to improve the resilience of the system.

Skill transfer and re-learning.

Task-specificity has been identified as essential in achieving sport or context-specific outcomes (Moradi et al., 2014). Phillips et al. (2010) stated that the time an individual spent on sport-specific training was able to discriminate whether they were an expert performer or not. While Proteau, Marteniuk, and Lévesque (1992) described the decrement in performance based on changing visual sensory feedback on skill performance, again indicating the importance of context-specific practice for a particular outcome. However, the DST, or the concept of degeneracy, offers a more integrated and fluid approach with regards to motor learning than that proffered by those advocating specificity.

As a consequence of some real and common issues in applied practice, skills often have to be practised, re-learnt or transferred (e.g., in injury rehabilitation; changing playing position) or combined to create new techniques. These problems can occur regardless of whether an individual is in a formal AD process, part of a PE curriculum or engaging in recreational activities. In light of the dynamic approach to acquiring and developing motor skills, the ability of an individual to capitalise on existing motor competence and their underlying neuromuscular abilities to support sport or context-specific movements may be necessary. Issurin (2013) stated that skill transfer could be usefully defined as the effect that developing one skill has on the subsequent learning and development of another skill. He continued to examine different types of skill transfer, describing positive and negative transfer, as well as lateral and vertical transfer. The nature or type of transfer may affect its usefulness in developing motor skill. Lateral and vertical transfer (Gagné, 1965) relates to transfer laterally across a wide range of tasks and situations while vertical transfer was supporting learning in higher-order skills. Issurin (2013) stated that the effectiveness of transfer in sport is differentiated on the stage of development of motor skills and level of motor abilities. These two points suggest that low to medium level athletes can transfer learning more effectively than their highly trained counterparts.

The importance of possessing a broad range of underpinning motor competencies to facilitate the transfer of learning to more complex tasks has been previously acknowledged. Giblin et al. (2014) stated that the opportunity for individuals to undertake cogitatively challenging movement skills in novel tasks or environments increases their ability to display mastery in a broad range of activities. As a consequence, it is suggested that engaging in the broad range of opportunities to practice and experience movement challenges is positive, and potentially facilitates the transfer of these competencies into more sport-specific skills.

As a sporting example of skill transfer and the usefulness of underlying neuromuscular attributes, performance in agility or CoD movements are worthy of further consideration. For example, several studies have demonstrated that strength does not directly improve performance in running or CoD movements (Hori et al., 2008;

Spiteri et al., 2013). Henry et al. (2016) identified that reactive strength had a minimum impact on reactive agility performance and suggested several skills such as balance, coordination, and cognitive abilities were more important. Correspondingly, it could be some other secondary underpinning or related quality that strength training may indirectly support which is a transferable asset; the development and non-specific training of this quality will manifest itself in serving better CoD. This quality could be, for instance, co-contraction of agonistic and antagonistic muscles around a joint or hip lock described as NMT by some practitioners (Bosch, 2014; Van Hooren & Bosch, 2016). With this in mind, the benefit of possessing an abundant general motor ability (GMA) to support the learning of new and novel skills warrants examination. Berry et al. (2008) examined perceptual and decision-making ability in Australian Football League. Those expert decision makers had a broader experience in invasion sports than those athletes who had less well-developed perceptual skills. The expert performers had a mixture of experience in more structured and deliberate play activities. They suggest that the broader experience, other than in Australian Football League, support the transfer of these specific skills from other sports. However, some research demonstrates the divergence in physical attribute and CoD performance, suggestive of the need for specificity in training to ensure high levels of transfer to sport-specific contexts (Loturco et al., 2018). Young and Farrow (2013) reiterated the importance of sport and context-specific movements for sports performance, specific movements involving decision making and reactivity are different to pre-planned CoD (considered more general movements). They detailed data which showed low variance in more generalised measures and high variance in more sport specific capacities.

It is interesting to note that Scanlan et al. (2014) stated that, though performance on a reactive agility test may relate to gameplay performance, that is it is considered a context-specific evaluation. That higher standard basketballers who performed better on the reactive agility test also show improved transferable skills. Even more interesting is the fact that Scanlan et al. still consider the reactive agility test may lack sufficient specific movements. It is my opinion that this represents a positive relationship with context-specific skills and their transferability and association into other performance tasks, see Section 4.1.1 for precedence.

As this point is important to acknowledge that in this study the focus is on the potential role GMA has in facilitating the performance in a novel task. Specifically, the acute improvements in a novel task over repeated trials and how that relates to level of participants GMA level. This is more aligned to the concepts of DST and degeneracy, in context of GMA; where FMS or developed sub-components that are possessed by a participant support their ability to improve performance on a novel movement challenge. There is not any implication in this investigation on the role of GMA and its impact on the ability of an individual to learn motor skills over a period of time; this would be a different process.

6.1.3 Mechanical determinants of a novel task incorporating CoD.

In Chapter Four kinematics of preplanned and reactive CoD were examined. It was concluded that those individuals who performed well on these CoD task demonstrated high variability in kinematic outcomes, velocity and lateral foot displacement (Cazzola, Pavei, & Preatoni, 2016; Preatoni et al., 2013). Therefore, rather than involve particular kinematic measures of the CoD technique, this chapter utilised more generalised measures of mechanical determinant when investigating CoD in a novel task. These measures included peak velocity and average deceleration before two *sharp* CoD (180° & 135°) manoeuvres within a complex and reactionary task.

CoD movements do not necessarily require an individual to have a high maximum velocity, as most of these tasks are undertaken over very short distances (Little & Williams, 2005). Therefore, the ability to reach a maximum velocity running technique, which is different to that required for acceleration or deceleration, is not required. However, the ability to maximise acceleration in these CoD movements and create the highest velocity possible is beneficial. This usefulness of high velocity is particularly important when considering maintaining velocity into and out of the actual CoD event (see Section 4.4.3) (Vanrenterghem, Venables, Pataky, & Robinson, 2012). It has been shown that "Increasing force application during the braking phase of COD movements has been shown to increase exit velocity during COD movements" (Spiteri et al., 2015; p. 2211) due to an increase in stored energy during the steps before and during the CoD. This storing of elastic energy, under eccentric contractions, could be considered as directly effecting deceleration to better sustain running velocity and control during direction changes (Hewit, Cronin, Button, & Hume, 2011), as Spiteri, Newton, and Nimphius (2015) stated that “faster athletes utilized this stored elastic energy during the braking phase of the movement” (p. 634). Assessing maximum or peak velocity and average deceleration may, therefore, be excellent kinematic indicators of CoD ability. In describing the impact of peak velocity in CoD, it is essential to further acknowledge the role of deceleration, especially in those CoD movements that involve 180° turns such as in a 5-0-5 agility test, and as such recognise the role of developing and increasing concentric and eccentric strength qualities (Spiteri et al., 2015).

Implicitly these CoD manoeuvres require significant amounts of deceleration in any given direction before re-acceleration in the new direction. Therefore an ability to decelerate proficiently is a requirement of a good 180° CoD performance (Hammami et al., 2017; Harper & Kiely, 2018). Deceleration has received less attention than acceleration, from a mechanical perspective, though the impact of deceleration, underpinned by appropriate neuromuscular abilities, is seemingly crucial in CoD movements (Harper, Jordan, & Kiely, 2018; Hewit et al., 2011; P. Jones, Thomas, Dos'Santos, McMahon, & Graham-Smith, 2017; Spiteri et al., 2014). The mechanical determinants of CoD speed and CoD performance times have previously been identified to include, for example, shorter ground contact times in the pre and final foot contact in a CoD task, greater horizontal propulsive forces and larger horizontal braking forces in the pre-CoD foot contact (Dos'Santos, Thomas, Jones, & Comfort, 2017). This greater braking force in the penultimate step before the CoD perhaps indicates there would be a more substantial whole-body deceleration in the final step of those athletes with a higher CoD speed. This deceleration ability, as a function of better CoD performance, has been previously recognised (Nedergaard, Kersting, & Lake, 2014) particularly concerning the mechanics before the actual CoD turn (Jones et al., 2017). Sayers (2015) also proposed that whole body deceleration during a CoD task was a critical component of CoD ability, and this was reflected in previous findings that had identified acceleration was an essential factor in CoD tasks. Therefore, evaluating the deceleration of a performer in a CoD task may serve to highlight those with a greater ability to control their velocity, capitalising on their physical attributes (e.g., Kovacs, Roetert, & Ellenbecker, 2008). Measurements of deceleration may, therefore, serve to distinguish better performers on a CoD task (P. Jones et al., 2017).

6.1.5 Study aims.

It is proposed that performers with better GMA have the potential to immediately adapt to new skills in a variety of sport or context-specific situations better than performers with lower GMA. It is speculated that higher GMA facilitates learning and transfer of motor skill, allowing performers to adapt to the challenge of undertaking a new or novel skill in an integrated manner. This adaptive ability to affect performance will be accompanied by changes in kinematic factors that represent the mechanical execution of the novel task. Therefore, I hypothesised that participants with higher GMA would perform better on a novel task than lower GMA participants as measured by (a) better performance time across six repeated trials, and (b) higher peak velocity and average deceleration across six repeated trials in two separate CoD tasks.

6.2 Method

6.2.1 Participants.

The sample consisted of 38 participants (mean ± SD; age: 20 ± 2 years; body mass: 70.84 ± 13.18 kg; height: 175.83 ± 7.99 cm) who were physically active students. Using inclusion criteria participants were deemed suitable to take part in the study if, they were: (a) free of significant injury for a period of three months prior to the commencement of the study, (b) physically active i.e., they engaged in a minimum of 150 min. of high-intensity activity over a week and, (c) familiar with agility type movements. This inclusion criteria allowed for the selection of participants who were suitable to under the novel task, but without any prerequisites to have been engaged in a structured development programme. Before testing each participant was required to attend one familiarisation session, where the testing protocols were explained and rehearsed. The participants read the description of the aims and objectives, risks, and basic procedures of the study and a Physical Activity Readiness Questionnaire was completed, and informed consent was gained. The study was approved by the School of Sport ethics committee at York St John University and also by the Business, Arts, Humanities and Social Science ethics committee at the University of Central Lancashire.

6.2.2 Instrumentation.

Participants completed the Western Motor Ability Test (WMAT; Campbell & Tucker, 1967), and a series of a novel task (see Figure 6.1). The dependant performance measure of the novel task was the overall performance time (PT) to complete the task. PT on each attempt was recorded. Kinematic measurements of the participants' performance were also measured and recorded. Subsequent analysis of the repeated performance evaluated each participant's ability to improve their PT and any corresponding change in the kinematics of CoD. The impartiality or decontextualised element of the novel movement task is important (Kluwe et al., 2012) where the task has relevancy but is untrained. The participants were also assessed on their GMA using the WMAT, further analysis compared cohort specific GMA level with a repeat performance on the novel task. This study used a repeated design to compare the performance on a GMA test and performance on a novel new movement task.

Novel Task.

The task included forwards and backwards sprinting (backpedalling) (Hammami et al., 2017; Sekulic et al., 2014), involving acceleration and decelerating, two CoD, and a reaction to a stimulus. Individually, participants performed a maximum effort 10 m sprint, before decelerating to a stop at 4 m, where they performed an 180^0 CoD. This CoD was followed by a back-peddle for 4 m into a reactive CoD action (45° cut to the left or right) before a subsequent 5 m sprint to finish (see Figure 6.1.). Though the participant was backpeddling this second CoD manoeuvre can be deemed as a 135° CoD. The second CoD action was randomly selected using a timing system and signalled using an automated LED system (Microgate, Switzerland). The stimulus was presented on completion of the backpedal, initiated automatically by the timing system. PT of the task was recorded using a timing system (Microgate, Switzerland). The novel task was devised and constructed based up common elements and movements in agility and CoD activities and assessments (Nimphius et al., 2018), combined in a unique pattern. All six PT was used for further analysis. The kinematics of the CoD was assessed via a radar gun (Stalker Pro, USA). The radar gun (46 Hz) was positioned in-line with the line of action of the initial sprint, deceleration and back-peddle. A successful novel task was defined by initial 10 m acceleration sprint times being within 105% of the participant's benchmark 10 m time without deceleration. Two kinematic variables were scrutinised for velocity and deceleration. Peak velocity ($PVel_1$) in the initial acceleration period was identified and recorded from the continuous assessment of velocity from radar data, as was the peak velocity ($PVel_2$) in the second acceleration while participants back-peddled. Deceleration ($Decel_1$) following the first 10 m sprint into the first CoD was calculated. Deceleration was calculated by identifying the difference in velocity (lowest velocity during CoD - $PVel_1$) divided by the time interval over which the changed occurred. $Decel_2$ was calculated from the second sprint, while back-pedalling, into the second CoD. $Decel_{1\ and}$ $Decel_2$ can be considered average deceleration measures.

GMA test.

Participants completed the WMAT (Campbell & Tucker, 1967) as described in Section 3.2.3 and detailed in Appendix B. This test consists of (a) an agility run, assessed by the total time to complete the course, (b) a standing broad jump, measured using a measuring tape as the horizontal distance covered, (c) an alternate handball toss, with the duration of the test measured with a stopwatch and number of catches recorded by a single researcher; and, (d) a seated basketball throw measured using a measuring tape, and assessed as the horizontal distance from the throw line to initial landing point in the basketball throw.

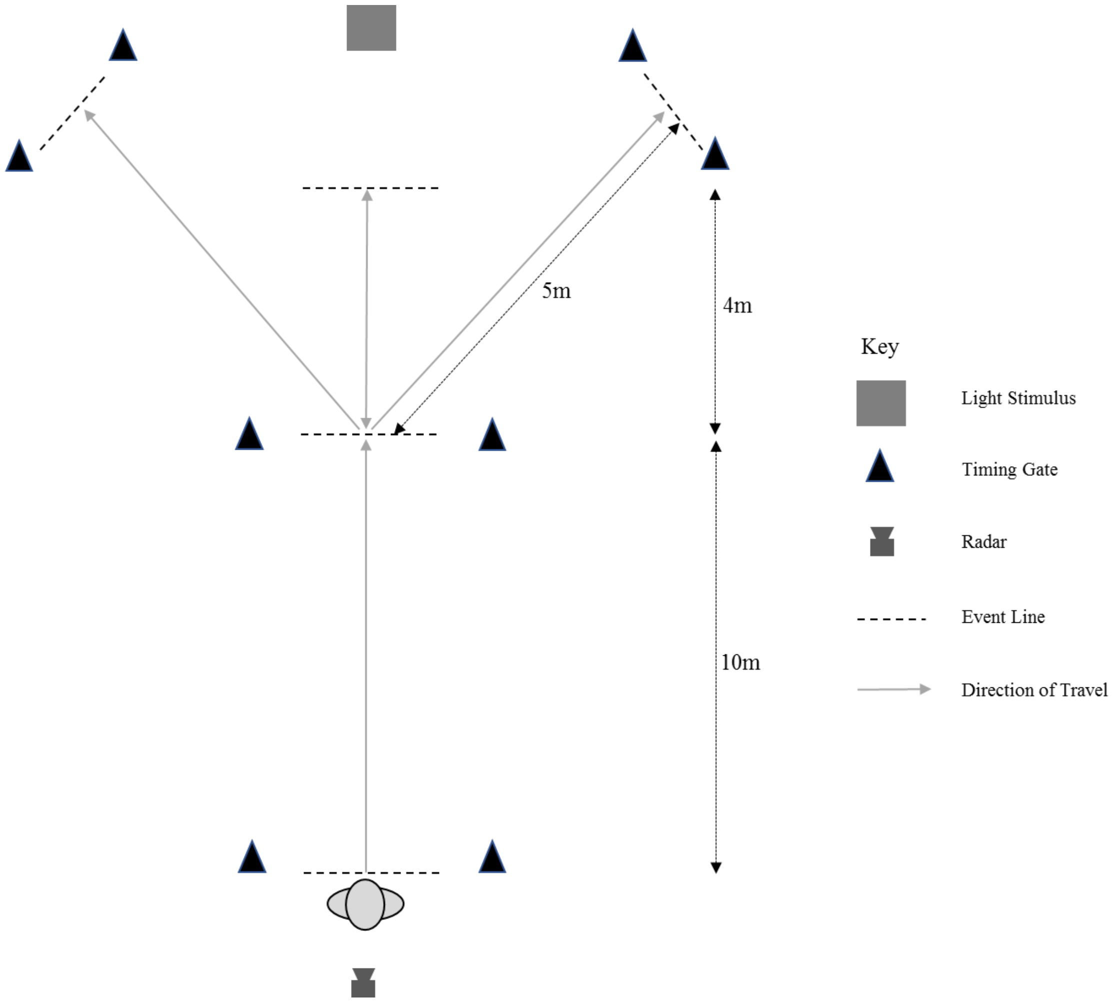

Figure 6.1. Novel task layout, running direction and data collection

6.2.3 Protocol.

Each participant completed the series of physical tests, and this was completed over two testing sessions, thus ensuring adequate rest between testing sessions. All testing took place on an indoor surface, with participants wearing shorts, skintight tops, and indoor training shoes. Each testing session began with a standardised 10 min dynamic warm-up, including running, bounding and dynamic stretching, followed by the respective experimental protocol. Participants completed the novel task six times, and each attempt was separated by at least 15 min, with the order randomised throughout testing. Participants also completed the four component tests of the WMAT as a circuit, and at least 15 min separated from each test. Testing occurred over two different sessions separated by one week, thus ensuring that adequate rest was allowed between WMAT and novel task.

6.2.4 Data analysis.

Statistical analyses were performed with SPSS Version 24 (IBM Corporation, Armonk, NY, USA). Preliminary analyses for normality (Kolmogorov-Smirnov) and homoscedasticity were performed. Individual WMAT scores were processed as in Chapter Three (see Section 3.2.4). Two groups were created based upon WMAT performance, high GMA (GMA_H) and low GMA (GMA_L), based upon a median split of GMA ranking. This dichotomous split was based upon a conceptual division of high and low GMA of participants, which reflects the rationale for study. Therefore, reference in this study to GMA_H and GMA_L are cohort specific. The performance variables (PT, $Decel_1$, $Decel_2$, $PVel_1$ & $PVel_2$) are dependent, while GMA is the independent variable. These performance variables evaluated the difference in GMA groups for clusters of dependent variables over repeated trials. The relationship between the modifications in repeat performance measures (dependent variables) and the independent variable of the novel task served as an assessment of skill learning for GMA groups.

Performance variables across trials were considered nested within participants and a hierarchical data structure. Therefore, multilevel growth models were employed to discover whether there were intra-individual differences in performance variables across six trials (level 1 or unconditional model including only time). Subsequently, whether the level of GMA could predict these changes (level 2 model includes GMA_H and GMA_L groups; see Bickel, 2007). Multilevel growth models were built using methods described previously (Peugh & Enders, 2005). The fixed components of level 1 models are represented by a normal regression equation structure and describe a participant's PT as a function of the intercept (i.e., initial status, β_{0J}), the slope (i.e., the growth rate,

β_{1J}), and a time-specific residual (e_{1j}). These are denoted $Y_{1j} = \beta_{0J} + \beta_{1J}TIME_{1j} + e_{1j}$. The random components of level 1 models examine whether there is individual variation in terms of the intercept (u_{0j}) and the slope (u_{1j}) and are denoted by the respective equations $\beta_{0J} = \gamma_{00} + \gamma_{0j}$ and $\beta_{1J} = \gamma_{10} + u_{1j}$. γ_{00} and γ_{10} denote mean initial intercept and mean initial slope, respectively (Page, 2017).

The level 1 growth rate (β_{1J}) was initially examined to establish if there was an association in PT across the repeated trials. If a significant relationship was identified, the intercept (u_{0j}) and slope (u_{1j}) were then tested to establish if individuals differed regarding their initial performance variable and subsequent growth rates. If significant relationships were discovered at this stage, for u_{0j} and u_{1j}, the model was tested for fit using a chi-square likelihood ratio test. The Level 2 predictor variables were then added if there was an appropriate model fit. A significant interaction term at level 2 indicated whether the predictor variables were related to growth in the repeated measures at level 1. SPSS Syntax for these models is presented in Appendix E. When no intra-individual differences between trials were found, multiple mixed design analysis of variance (ANOVA) was then performed.

Finally, Pearson's correlation coefficients (*r*) assessed the strength of association between WMAT and PT, Decel1, Decel2, PVel1 & PVel2, respectively. The *r* and F statistics were interpreted according to the values suggested by Cohen (1992) where 0.1 = small, 0.3 = moderate and 0.5 ≥ large when using a correlation coefficient and ANOVA. Statistical significance of 95% was used ($p < .05$.

6.3 Results

6.3.1 Preliminary results.

All data were normally distributed and homoscedastic.

6.3.2 Main results.

Table 6.1 reports the correlation coefficient for all variables. Except for $Decel_1$ (trial 4) and $Decel_2$ (trials 1, 2 & 4), all other relationships were moderate to large. Multilevel modelling for each dependent variable is presented in Table 6.2, all models were estimated, and the entirety of data for each model is reported, regardless of significance. For PT unconditional linear growth models showed that there were significant changes in PT over the six trials (β_{1J} = -0.03, p < .01). There was significant variability between participants in terms of the intercept (u_{0j} = 0.11, p < .01), but not the slope (u_{1j}). For $Decel_1$ unconditional linear growth models showed no significant changes over the six trials. For $Decel_2$ unconditional linear growth models showed that there were significant changes in deceleration over the six trials (β_{1J} = -0.10, p < .01). However, there was no significant variability between participants in terms of the intercept (u_{0j}) and the slope (u_{1j}) in the level 2 model. For $PVel_1$ unconditional linear growth models showed that there were no significant changes in peak velocity over the six trials. For $PVel_2$ unconditional linear growth models showed that there were significant changes in PT over the six trials (β_{1J} = 0.02, p < .05). There was significant variability between participants in terms of the intercept (u_{0j} = 0.06, p < .01), but not the slope (u_{1j}).

As the unconditional linear growth models (Level 1) for $Decel_1$ and $PVel_1$ were not significant, nor was there any significant variability in $Decel_2$, three mixed design repeated ANOVAs were used. For $Decel_1$ Table 6.3 reports a significant difference in GMA groups (F(1, 36) = 6.41, p < .05) with a small ES (.15). There was no significance between trials or interaction with GMA groups and trials. $Decel_2$ had a significant difference across trials (F(5, 180) = 2.65, p <.05) trivial ES (.07), but no significance between GMA groups or interaction with GMA groups and trials. For $PVel_1$ Table 6.3 reports a significant difference in GMA groups (F(1, 36) = 12.21, p <

.05) with a small ES (.25). There was no significance between trials or significant interaction with GMA groups and trials.

Table 6.1.

Pearson's correlation coefficients (*r*) for WMAT and performance variables (PT, $Decel_1$, $Decel_2$, $PVel_1$ & $PVel_2$)

Variable	**Trial**					
	1	2	3	4	5	6
PT (s)	$-.59^{**}$	$-.66^{*}$	$-.62^{**}$	$-.61^{**}$	$-.62^{**}$	$-.67^{**}$
$Decel_1$ ($m \cdot s^{-2}$)	$-.49^{**}$	$-.55^{**}$	$-.41^{*}$	-.20	$-.49^{**}$	$-.40^{*}$
$Decel_2$ ($m \cdot s^{-2}$)	-.26	-.15	$-.49^{**}$	-.17	$-.33^{*}$	$-.46^{**}$
$PVel_1$ ($m \cdot s^{-1}$)	$.63^{**}$	$.63^{**}$	$.67^{**}$	$.62^{**}$	$.64^{**}$	$.56^{**}$
$PVel_2$ ($m \cdot s^{-1}$)	$.57^{**}$	$.61^{**}$	$.69^{**}$	$.48^{**}$	$.56^{**}$	$.61^{**}$

N = 38
* $p < .05$, ** $p < .01$

Table 6.2.

Fixed Effects Estimates (Top) and Variance-Covariance Estimates (Bottom) for Multilevel Growth Models of the GMA Predictor on Indices of PT, $Decel_1$, $Decel_2$, $PVel_1$, and $PVel_2$.

Parameter	**PT**		**$Decel_1$**		**$Decel_2$**		**$PVel_1$**		**$PVel_2$**	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Fixed effects										
Intercept (β_{0J})	6.65 (0.07)***		-4.01 (0.12)***		-2.58 (0.12)***		6.51 (0.06) ***		3.24 (0.05)***	
Level 1										
Time (β_{1J})	-0.03 (0.01)**		-0.01 (0.02)		-0.10 (0.03)**		0.01 (0.01)		0.02 (0.01)*	
Level 2										
Time		-0.03 (0.01)*		-0.01 (0.03)		-0.04 (0.04)		0.005 (0.01)		
GMA		-0.36 (0.12)**		-0.50 (0.23)*		0.13 (0.24)		0.38 (0.11)**		0.28 (0.09)*
Time*GMA		-0.00 (0.02)		0.01 (0.04)		-0.12 (0.06)		0.002 (0.01)		0.01 (0.02)
Random parameters										
Residual (e_{1J})	0.04 (0.004)***	0.04 (0.00)***	0.24 (0.03)***	0.24 (0.03)***	0.57 (0.07)***	0.57 (0.07)***	0.03 (0.003)***	0.03(0.003)***	0.04 (0.004)***	0.04 (0.004)***
Intercept (u_{0j})	0.14 (0.04)***	0.11 (0.03)**	0.37 (0.13)**	0.31 (0.12)*	0.04 (0.13)	0.04 (0.13)	0.13 (0.003)***	0.09 (0.03)**	0.06 (0.02)**	0.05 (0.02)**
Slope (u_{1j})	0.001 (0.003)	0.003 (0.00)	-0.02 (0.02)	-0.02 (0.02)	0.01 (0.03)	0.01 (0.03)	0.003 (0.003)	0.002 (0.003)	-0.001 (0.002)	-0.002 (0.002)
Covariance of intercept and slope	0.0001 (0.001)	0.001 (0.003)	0.004 (0.004)	0.004 (0.004)	0.01 (0.01)	0.004 (0.01)	Redundant	Redundant	Redundant	Redundant
(df) -2*log likelihood	(38) 21.96	(38) 12.71	(38) 411.86	(38) 405.64	(38) 564.39	(38) 559.43	(38) -39.69	(38) -50.89	(38) 0.41	(38) -16.45

Notes. Standard errors are in parentheses
N = 38
* $p < .05$ **. $p < .01$ *** $p < .001$

Table 6.3. Descriptive statistics, *F* values and ES

Variable	**Trial**												***F* Values (ES)**		
	1		2		3		4		5		6		Trial	Group	Trial*Group
	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI			
PT (s)															
Overall	6.62 (0.41)	6.49, 6.76	6.58 (0.42)	6.44, 6.71	6.60 (0.51)	6.43, 6.77	6.54 (0.46)	6.39, 6.69	6.52 (0.42)	6.38, 6.66	6.47 (0.43)	6.33, 6.61			
GMA_H	6.46 (0.40)	6.27, 6.66	6.40 (0.38)	6.22, 6.58	6.36 (0.34)	6.20, 6.53	6.35 (0.38)	6.17, 6.54	6.35 (0.33)	6.19, 6.51	6.29 (0.32)	6.13, 6.44			
GMA_L	6.78 (0.37)	6.61, 6.96	6.75 (0.39)	6.57, 6.94	6.84 (0.55)	6.57, 7.10	6.72 (0.47)	6.50, 6.95	6.69 (0.43)	6.48, 6.90	6.65 (0.45)	6.43, 6.87			
$Decel_1$ (m·s^{-2})													0.87 (.02)	6.41 (.15)*	0.32 (.01)
Overall	-3.93 (0.74)	-4.18, -3.69	-4.09 (0.76)	-4.34, -3.84	-4.10 (0.72)	-4.33, -3.86	-4.08 (0.73	-4.32, -3.84	-3.94 (0.70)	-4.17, -3.71	-4.07 (0.80)	-4.34, -3.81			
GMA_H	-4.17 (0.58)	-4.45, -3.89	-4.32 (0.61)	-4.61, -4.03	-4.36 (0.65)	-4.67, -4.04	-4.23 (0.71)	-4.57, -3.89	-4.22 (0.58)	-4.49, -3.94	-4.25 (0.79)	-4.31, -3.87			
GMA_L	-3.69 (0.83)	-4.09, -3.29	-3.86 (0.83)	-4.26, -3.46	-3.84 (0.71)	-4.18, -3.50	-3.93 (0.73)	-4.28, -3.58	-3.66 (0.72)	-4.01, -3.31	-3.87 (0.79)	-4.28, -3.51			
$Decel_2$ (m·s^{-2})													2.65 (.07)*	3.22 (.08)	1.34 (.04)
Overall	-2.81 (0.76)	-3.06, -2.56	-2.71 (0.68)	-2.94, -2.49	-2.81 (0.78)	-3.07, -2.55	-2.96 (0.84)	-3.24, -2.68	-3.17 (1.20)	-3.56, -2.77	-3.23 (0.99)	-3.56, -2.91			
GMA_H	-2.80 (0.70)	-3.14, -2.46	-2.72 (0.64)	-3.02, -2.41	-3.09 (0.69)	-3.42, -2.76	-3.01 (0.91)	-3.45, -2.57	-3.36 (1.10)	-3.89, -2.83	-3.58 (1.09)	-4.10, -3.05			
GMA_L	-2.82 (0.84)	-3.22, -2.41	-2.71 (0.74)	-3.07, -2.35	-2.53 (0.79)	-2.91, -2.15	-2.91 (0.79)	-3.29, -2.53	-2.98 (1.29)	-3.60, -2.35	-2.89 (0.76)	-3.25, -2.52			
$PVel_1$ (m·s^{-1})													0.98 (.03)	12.21 (.25)*	2.00 (.05)
Overall	6.49 (0.38)	6.37, 6.62	6.53 (0.41)	6.40, 6.66	6.58 (0.46)	6.43, 6.73	6.53 (0.41)	6.39, 6.66	6.54 (0.46)	6.39, 6.69	6.54 (0.42)	6.40, 6.68			
GMA_H	6.67 (0.22)	6.56, 6.77	6.70 (0.26)	6.57, 6.82	6.82 (0.38)	6.63, 7.00	6.74 (0.34)	6.58, 6.91	6.77 (0.34)	6.60, 6.93	6.68 (0.30)	6.54, 6.83			
GMA_L	6.32 (0.43)	6.11, 6.523	6.36 (0.46)	6.14, 6.59	6.34 (0.42)	6.14, 6.54	6.31 (0.36)	6.14, 6.48	6.30 (0.44)	6.09, 6.52	6.39 (0.48)	6.16, 6.63			
$PVel_2$ (m·s^{-1})															
Overall	3.28 (0.31)	3.18, 3.38	3.26 (0.31)	3.16, 3.36	3.29 (0.35)	3.17, 3.40	3.33 (0.33)	3.23, 3.44	3.33 (0.31)	3.22, 3.43	3.37 (0.32)	3.27, 3.48			
GMA_H	3.39 (0.26)	3.27, 3.52	3.41 (0.30)	3.27, 3.56	3.50 (0.29)	3.37, 3.64	3.47 (0.28)	3.34, 3.61	3.46 (0.25)	3.34, 3.58	3.54 (0.32)	3.39, 3.70			
GMA_L	3.17 (0.31)	3.02, 3.32	3.11 (0.23)	3.00, 3.22	3.07 (0.26)	2.95, 3.20	3.20 (0.32)	3.04, 3.35	3.20 (0.32)	3.04, 3.35	3.20 (0.21)	3.10, 3.30			

N = 38
*$p < .05$

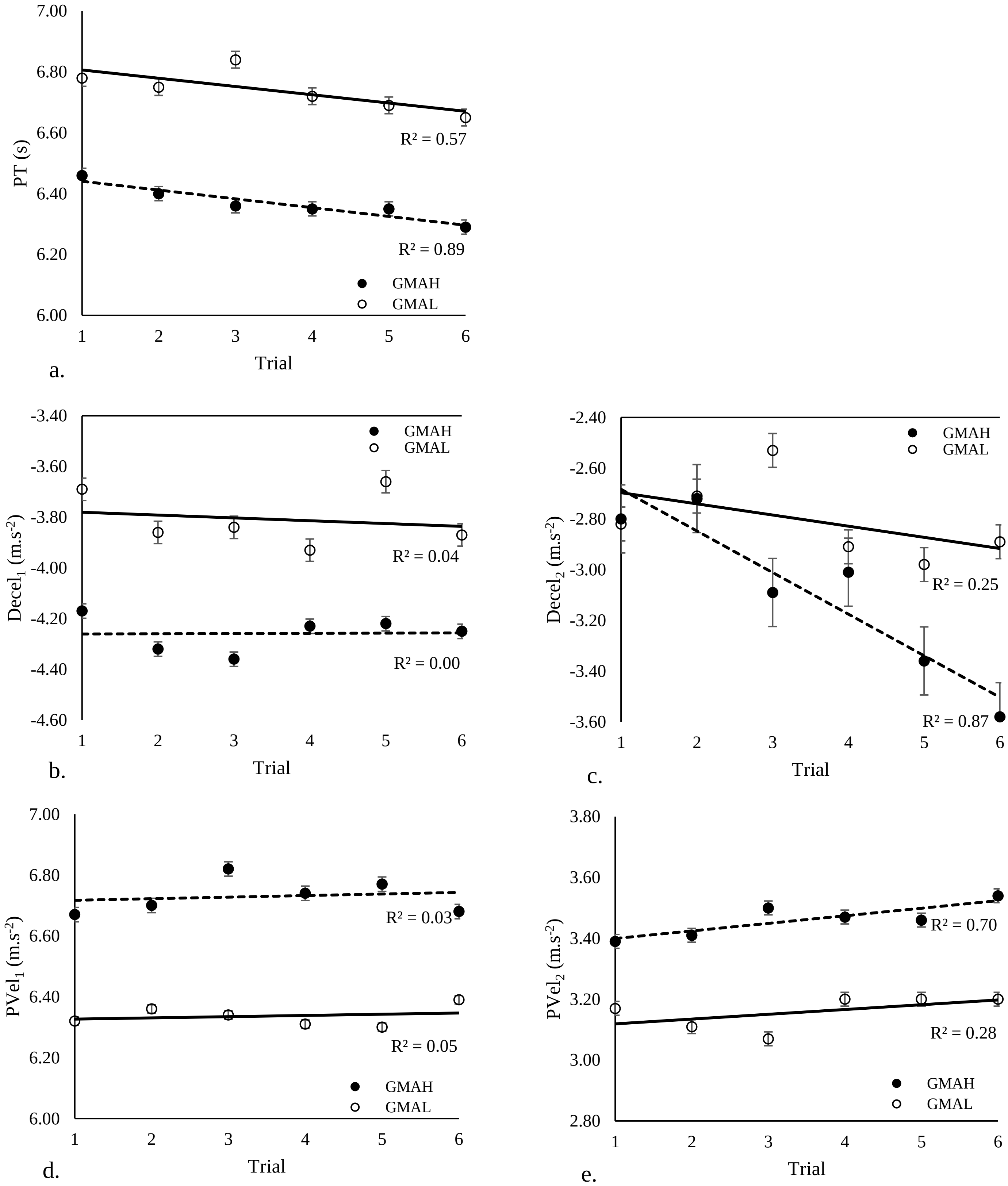

Figure 6.2. PT, $Decel_1$, $Decel_2$, $PVel_1$, and $PVel_2$ mean data for GMA_H and GMA_L across six trials.

6.4 Discussion

The study aimed to examine the effect of GMA on performing a novel and complex CoD task. It is conjectured that those possessing higher GMA would facilitate the learning of novel movement task through the transfer of generic movement skills in a novel motoric challenge. In the context of this study, GMA_H and GMA_L were identified on a medium spilt of the participant group. Consequently, a high or low reference to GMA is cohort specific. It should however be noted that the mean WMAT score for the whole group was 64.38 (SD = 13.87) Sigma score (GMA_H = 74.31 (SD = 4.87), $GMA_{L\,=}$. and specifically, the mean WMAT score for the GMA_H = 74.31 (SD = 4.87) and for GMA_L = 50.14 (SD = 9.23). The first hypothesis that participants with higher GMA would perform better on a novel task than lower GMA participants as measured by better performance time across six repeated trials was accepted, as there was a significant difference between GMA_H and GMA_L (β_{1J} = -0.36 (0.12), $p < .01$). Figure 6.2a shows the extent of the difference between groups and the change in PT over the six trials. Each group's PT decreased significantly over the trials (β_{1J} = -0.03, $p < .01$). The difference in the two groups was evident from the first trial (GMA_H = 6.46s, SD = 0.40; GMA_L = 6.78s, SD = 0.37), which indicated that GMA_H performed significantly better than GMA_L immediately on the novel task. Although the relative difference between the groups remained comparable across the trials. The novel task may be construed as a combination of generic agility movements holistically representing a narrower set of movement challenges, i.e., specific agility (Liefeith et al. 2018). In Table 6.1 it can be seen that WMAT significantly negatively correlates with PT on all six trials. Using guidance from Wulf and Shea (2002) this novel task can be described as complex, highlighted by its multifaceted and specific nature. Therefore, it appropriately aligns with the innovative concept of specific agility presented in Chapter Two. Consequently, it is reasonable to assume that those possessing higher GMA perform better on this more specifically orientated task by successfully capitalising upon their generic movement experiences, FMS and NMT abilities (Barnett, van Beurden, Morgan, Brooks, & Beard, 2010). For example, employing better localised neuromuscular control (Bosch, 2014), refining motor skills (Diedrichsen & Kornysheva, 2015) or capitalising on superior braking utilising elastic components (Spiteri et al., 2015). These findings support the evidence presented in previously (see Chapter Two) namely, there is a direct and unambiguous link between generic and specific agility. The findings here suggest that transfer of motor skills, at least general to specific is a realistic concept reinforcing previously research (Barnett et al., 1973), but which are contrary to other previous findings (Ellison et al., 2017; Moradi et al., 2014; Proteau et al., 1992), who have advocated the principle of specificity (Henry, 1958). In a related study Gagné (1965) referred to lateral and vertical transfer in motor skills, where the lateral transfer in this case represents a broad range of movement experiences encapsulated by GMA, which essentially support successful outcomes in more complex task through vertical transfer. Berry et al. (2008) described the functional importance of a broad sampling of sporting experiences in facilitating the transfer of skills across activities, explicitly highlighting the vital role of pattern recall and recognition transfer. It is interesting to note that Berry et al. (2008) highlight that this transfer potential is explicitly different from the concept of deliberate practice.

The six repeated trials in this study's protocol were separated by 15 min, specifically to reduce the effect of chronic learning (Magill, 2001) and to minimise any training or fatigue effect (Ross, Leveritt, & Riek, 2001). With this in mind, the ability of the GMA_H to improve their absolute PT may represent the ability of better GMA performers to dynamically engage in producing a superior movement solution to this novel task, whereas the GMA_L did improve their PTs but these were all relatively slower than GMA_H. This manifestation of a participant's ability to dynamically organise components of motor competence, as represented by their FMS and neuromuscular abilities in order to accurately respond to an unfamiliar complex movement is a valuable asset in developing performance. Kim, Chen, Verwey, and Wright (2018) stated that “an important consequence of extensive physical practice is the emergence of transient functional connectivity and structural adaptation between and within neural networks to support skilled motor behaviour" (p. 55). As discussed in Section 2.5.1, the ongoing plasticity of the neural system to be adaptable is potentially a critical element in the leaning and re-learning of motor skills. Preatoni et al. (2013) discussed how the dynamical systems approach suggests that variability represents the range of possible coordination patterns that can be employed to undertake any particular motor task. The neural networking solutions that are available offer a mechanism where this adaptable functionality is founded. Though there were elements within the novel task which would have been familiar to the participants (e.g., 180° CoD, 135° CoD), as they met the inclusion criteria for the study, the unique combination of these CoD requirement serves to make this a novel task for each participant. The complexity of the overall movement compounded by the cognitive aspect, in the form of the reactive element, further highlights the novelty of the task. Acknowledging this complexity reinforces the importance of these findings, that GMA serves sport-specific movements that involve multiple CoD as utilised in RL (Serpell, Ford & Young, 2010), regardless of the level of practice in a movement challenge.

However, the consecutive evolution in PT in both groups was similar, whereas it was expected that there would be more of a divergent pattern in performance across trials and that the GMA_H would reach an asymptotic plateau in their PT sooner than $GMA_{L.}$ The findings demonstrate that both groups continued to improve, and may be indicative that neither group reached a maximum in their PT. Whereas the difference in the two groups was defined in the first trial of the novel task. Diedrichsen and

Kornysheva (2015) reviewed the nature of motor learning, highlighting the importance of hierarchical skill encoding in defining the selection and execution phases of producing a novel motor output. Through chunking and modular representations of temporal and spatial sequences at an intermediate stage (Hirano & Funase, 2017), between the selection and execution phases, Diedrichsen and Kornysheva suggest that this facilitates early responses in new motoric challenges by utilising the previous embedded movement skills in a new synergy of execution patterns. In this study, it is suggested that the sub-routines employed in the final solution to the novel task benefited both groups, but that the more established generic routines in the GMA_H proved more productive.

Previously complex motor skills like the novel task have been shown to require specialised motor skills, and therefore specific training. The inference being that there is a limited transfer of motor skills and neuromuscular capability from general to specific practice (Loturco et al., 2018). However, the findings in this current study demonstrated that those individuals with better GMA perform better on this novel task that involves specialist CoD movements. That is the level of GMA facilities the performance of this novel and new task, through some potential transfer of abilities to the specific requirements of this task. There is some ambiguity in the advice of Loturco et al. (2018) with regards to skill transfer, as they do advocate "a wider variety of exercises that mimic the movements performed during official matches in training routines" (p. 231) while also presenting data which shows a weak correlation between linear speed, power and CoD ability. In describing a weak relationship with underlying physical attributes and CoD, Loturco et al. are seemingly calling for a broader range of specific motor skills rather than generic competencies. However, they do summarise by describing a combined effect of various attributes being the best for training and ultimately for performance. This approach may be interpreted as combining generic and specific agility training to maximise the effect on performance.

In the second hypothesis the mechanical execution of the novel task was examined, helping establish the relationship between GMA and how the movement was performed. Barnett et al. (2010) described this as a process-orientated evaluation, observing how specific mechanical elements in the overall motor skill were executed to influence PT. Therefore, the second hypothesis, that participants with higher GMA would perform better on a novel task than lower GMA participants as measured by higher peak velocity and higher average deceleration across six repeated trials, was accepted. It should be noted that the distance covered and the duration of the first and second CoD movements were different and therefore may have affected the outcome of performance on each section, notwithstanding this, the discussion below highlights difference in GMA_H and GMA_L performance and offers justification for this disparity.

Within the novel task, the ability of participants to reach a high peak running velocity and decelerate in the initial CoD movement was a defining factor in overall PT (Hewit et al., 2011; Jones et al., 2017), more specifically a crucial factor between GMA_H and GMA_L. $PVel_1$ and $Decel_1$ were both significantly different between GMA_H and $GMA_{L,}$ $F(1,36) = 12.21$, $p < .05$, .25 ES and $F(1,36) = 6.41$, $p < .05$, .15 ES respectively, although there was no significant difference across trials (see Table 6.3). This initial CoD involved a forward sprint into a 180° CoD. As previously highlighted, Dos'Santos et al. (2018) described the mechanics of a CoD task as being both velocity and angle dependent. They describe a situation where larger entry velocities, require larger deceleration into a direction change when associated with larger CoD angles, such as a 180° turn. The GMA_H were seemingly quicker and had greater deceleration in the initial CoD movement than $GMA_{L,}$ Dos'Santos et al. (2018) propose this type of mechanical outcome reflects superior neuromuscular abilities and it is suggested here that this is consistent with the proposal that GMA_H can capitalise on broader and more capable GMA (Harper & Kiely, 2018). However, other factors may inevitably influence this outcome, for example, less inhibition or more confidence in individual's ability. Indeed, an element proposed in this thesis is that GMA reflects these non-physical elements also (see Chapter Two). The difference between $GMA_{H\ and}$ GMA_L was evident from the initial trial, in both $Decel_1$ (GMA_H = -4.17m·s^{-2}, SD = 0.58; GMA_L = -3.69m·s^{-2}, SD = 0.83) and $PVel_1$ (GMA_H = 6.67 m·s^{-1}, SD = 0.22; GMA_L = 6.32m·s^{-1}, SD = 0.43) and the difference remained consistent across all other trials (see Figure 6.2b and 6.2d). The moderate to large correlations presented in Table 6.1 for $PVel_1$ and $Decel_1$ with WMAT provides further support for the concept that better GMA relates to improved mechanical performance in a new movement challenge. Speculatively it may have been expected that there was more or a divergent pattern across the trials, reflective of the two groups differing abilities to transfer their motor competency.

In the second CoD movement during the novel task participants were required to backpedal into a large CoD, while reacting to a light stimulus, subsequently running forwards in the new direction. Backpedalling is a common movement associated with *agility* and CoD training (Graham, 2000; Jeffreys, 2006), being described as elementary movement pattern which contributes to a holistic agility movement. Backpedalling has been shown to have a higher cadence and short contact phase than forwards running, with speeds in Backpedalling being 80% of that of forwards running (Arata, 1999; Threlkeld, Horn, Wojtowicz, Rooney, & Shapiro, 1989). The difference in the nature of the two CoD tasks is reflected in the magnitudes of peak velocity and average deceleration (see Table 6.3) (Nimphius et al., 2018; Nimphius et al., 2016), lower peak velocities and deceleration as a consequence of backward running rather than forwards running. superior neuromuscular abilities Using multilevel growth modelling $PVel_2$ was the only mechanical variable to demonstrate a significantly different pattern over the six trials ($\beta_{1J} =$ 0.02 (0.01), $p < .05$) and significance difference between GMA groups ($\beta_{1J} =$ 0.28 (0.09), $p < .05$). Both groups were able to improve their peak velocity across the six trials, however the GMA_H had significantly greater $PVel_2$; this ability to accelerate over a short distance and reach high velocities, as previously discussed, are determinants of better CoD performance (Little & Williams, 2005; Vanrenterghem et al., 2012).

Figure 6.2c shows that the participants' ability to decelerate into the second CoD manoeuvre (135°), was also significantly different across six trials ($F(5,180) = 2.65$, $p < .05$, .07 ES), however there was no significant difference between GMA_H and GMA_L. Both groups had a similar $Decel_2$ in the first trial (see Figure 6.2c), though in subsequent trials the GMA_H increased their deceleration to a greater extent than GMA_L, the difference between the groups for final trial was $-0.35 m \cdot s^{-2}$. While the evolution of the of $Decel_1$, $PVel_1$ across the trials was consistent in both groups, the more divergent patterns in $Decel_2$ and the significant difference in improvement relative to groups in $PVel_2$ suggests that it is the performance of the second CoD movement in the novel task where the variance lies. This is different to previous findings, where greater braking forces have been identified in CoD with greater CoD angles (Schot, Dart, & Schuh, 1995). This second CoD was the point at which the reactive stimulus was initiated. The more considerable improvement in $Decel_2$ for the GMA_H participants, across trials, may suggest an ability to learn at different rate in this specific reactive element of the novel task, along with adapting to the mechanical demands of the movement. This may be particularly pertinent as the mechanical demands of backpedalling have been shown to be moderately different to forwards running. For example a more upright posture, shorter ground contact times and increased cadence (Threlkeld et al., (1989). Better deceleration while backpedalling over trials therefore show the GMA_H could apply their flexible neuromuscular abilities more effectively in this second movement (Dos'Santos et al., 2018) and subsequently influence PT. However it is interesting to note that $Decel_2$ only had small to moderate correlations with GMA across trials (see Table 6.1) despite this divergent patterns in the groups. Spiteri et al. (2015) suggested that mechanical properties may differ depending upon the CoD task being undertaken, which in turn may reflect the ability to adjust kinematics through superior physical qualities such as strength. This factor may provide a rationale for why the two CoD tasks may have produced different results from the novel task, but indicates better GMA allows for these adjustments to be made in a more adaptable participant. Accordingly, the performance of this novel task that involved reactive CoD, acceleration and deceleration movements describes a similar relationship to that identified in Chapter Four. Namely, the better GMA performers as measured on the WMAT, relates to better performance on a reactive CoD task, even when the task is novel.

6.4.1 Identification of athletic giftedness.

Interestingly, the correlations between WMAT and PT, $PVel_1$ and $PVel_2$, respectively, were all significantly large across all six trials. Though Hands et al. (2018) suggest GMA cannot be directly assessed, the insight that WMAT strongly relates to key mechanical factors may support the notion that such test of GMA can be used for the discrimination of general athleticism and therefore identification for the suitability of an individual to be engaged in an AD programme. Therefore, the potential of GMA to assess athletic potential is reiterated, the discriminatory nature of a simple GMA field test to support selective measures should not be devalued or underestimated. However, interest in developing and revising tests of GMA is something that future research should consider further, particularly to ensure that an array of sub-capacities, FMS or *building blocks* are incorporated in these tests of GMA, so as to profile an individual's athleticism.

6.4.2 Method of analysis.

The choice of analytical technique should be noted in this study, the multilevel growth models were chosen as they offer several advantages over ordinary least squares regression analyses. Firstly, they do not require independence of observations, i.e., the same participant can be measured twice without confounding the data. This was a particular benefit whilst repeating measurements of performance variables on the same task and the same participants. Also, homogeneity of regression slopes does not have to be assumed, i.e., multilevel models explicitly model variability in regression slopes (Field, 2009). These benefits highlight the usefulness of multilevel modelling when examining repeated clustered variables in different groups.

6.4.3 Chapter summary.

GMA has the potential to discriminate performance in a novel task. Those with higher GMA significantly perform better than lower GMA participants when presented with a novel and complex task that incorporates elements of generic agility in a more specific combination. Despite the pattern of development or learning across repeated trials being similar in both groups, the GMA_H performed significantly better on all variables, PT, $PVel_1$ and $PVel_2$, $Decel_1$ and $Decel_2$, indicative of their better general motor competence and ability to employ these in new motoric challenges. The mechanisms supporting this relationship involve a dynamic interpretation of motor learning and the ability of the neuromuscular system to fully utilise a well mapped neural network. These points specifically may relate to improving the resilience in an individual's neuromuscular system, which may have an impact on reducing the risk of injury.

Chapter Seven

General Discussion, Implications and Recommendations for Future Study

This thesis aimed to re-examine the role of GMA and agility in athletes that are developing, specifically RL players. Providing evidence for the importance of GMA in balancing and supporting specialisation in AD. Five main objectives were identified:

1. To provide an overview of GMA and agility, including a reinterpretation of the agility construct.
2. To establish the importance of GMA in AD by examining the association between GMA, physical attributes and technical playing attributes in youth RL players.
3. To explore the mechanisms which may underpin GMA.
4. To investigate the development of GMA and explore the nature of longitudinal changes in GMA between youth RL players and youth school children.
5. To explore the role of GMA in acute skill transfer and describe its role in facilitating athlete resilience and adaptability in motor skill learning

Reflecting the objectives of the thesis, this chapter aimed to provide a general discussion of the findings of each study and provide some implications for applied and theoretical coaching practice in AD.

7.1 General Discussion and Implications

Building from my interests and professional experience as a practitioner in elite RL this thesis used empirical evidence to rationalise and validate my AD philosophy and to inform applied practice especially in RL. The aim was to offer coaches working with performers in structured AD programmes a training perspective that ensures specialisation and specificity of training is also balanced with well-developed and maintained GMA.

Henry's theory of specificity (Henry, 1958: Ellison et al., 2017), that supports specificity in training or motor development has had an influential bearing on coaches' and strength and conditioning practitioners' coaching practice: ensuring that deliberate practice of sport and context-specific situations is the norm in AD programmes (Ericsson et al., 1993; Henry, 1968). Rather than a broader range of skill development where there might be the possibility of skill transfer between practice opportunities (O'Keeffe et al., 2007), *targeted* and *authentic* training scenarios are devised ensuring direct relevance to the competitive goal (Moradi et al., 2014). Unfortunately, however the general athleticism of an individual to syncopate, coordinate and translate motor ability in a wide range of movement environments has diminished or is quickly replaced in younger individuals with specialised training. This results in movement specialists who are inflexible, less responsive to change and may be susceptible to injury. The assumption that sport-specificity is the definitive objective in AD, but that generalist training does not offer tangible and targeted support to performances in sport or context-specific environments, belies the fact that complex motor abilities required for these sport-specific movement complexes are founded on simple coordinative abilities, foundational base movements and fundamental physical attributes (Barnett et al., 2016; Giblin et al., 2014; Hands et al., 2018; Kirk & Rhodes, 2011; Magill, 2004; Santos et al., 2017). These foundations could be interpreted as what Burton and Rodgerson (2001) described as movement skill sets and movement skill foundations. Although simple basics are the foundations for complexity (Kirk & Rhodes, 2011), once on the road to developing complexity the simple foundations are seemingly quickly forgotten or scheduled out of the programme (e.g., Balyi & Hamiliton, 2004).

Of course the awareness of including and developing FMS, generic movement challenges, cognitive and behavioural training and neuromuscular training in an AD model is not innovative (Hopper et al., 2017; Lloyd et al., 2015; Lloyd et al., 2016). All appropriate AD programmes and models recognise the importance of these factors in developing competent movers who can progress their motor skills to an ever higher level of complexity or sophistication (Pichardo et al., 2018). However, this is focussed on children and youth performers in these models, creating the platform in the early years on which sport-specific performance can be developed. The assumption that the foundations on which higher order skills are built remain reliable and ever-present once established does not seem to be sensible or logical (Hands et al., 2018). All foundations must in the first instance be constructed appropriately to serve their function but over time these foundations should at the very least have their integrity checked. Do these foundations still exist and are they serving their original purpose? More importantly these foundations should be maintained in order that they can still perform their essential role of supporting the structures they were designed to sustain (Liefeith et al., 2018). Vandorpe et al. (2012) stated that FMS could be developed at any time in an individual's progress, i.e., they are not age-specific. This suggests that transition into the next phase of development is very much individualised and based on each person's level of motor competence and physical ability. However early specialisation and the focus on movement specificity, as artefacts of a contemporary AD approach (Lloyd et al., 2016) has led to the narrowing of athletes' GMA base. In short, the prospect that any general motor competence or FMS training is quickly withdrawn in favour of more specific training (see Section 2.4.2) compounds the ability of these AD programmes to remedy poor motor competence in athletes, thereby exacerbating the specialisation issue rather than make it better (Malina, 2014).

The impact of this early specialisation has led to GMA and the neuromuscular system remaining underdeveloped, and therefore the athlete's possible development being reduced or restricted effectively lowering their performance ceiling (Collins et al., 2012). In contrast, the evidence in this thesis suggests that improved GMA has the potential to facilitate a performer's capacity to transfer learning and may improve their ability to adapt to new specific and complex skills in a variety of sport-specific situations (see Chapter Six). Specifically, it is proposed here that enhancing GMA can be operationalised through a reinterpretation of the agility construct (see Section 2.3.1) to ensure the *health* of an individual's GMA.

The current definitions used to demarcate agility are either academic definitions that are too generic and broad or very applied interpretations which are too narrow and potentially restrictive (Benvenuti et al., 2010; Twist & Benickly, 1996; Young & Willey, 2010). An improved agility construct could potentially lead to many benefits in AD. Figure 7.1. illustrates that a blended and persistent approach of incorporating generic and specific agility training in an athlete's development programme serves to increase the breadth of GMA. This facilitates an increased movement vocabulary theoretically developing more robust athletes who can better transfer learning to sport-specific tasks. Avoiding the issues associated with a small GMA base, such as movement monotony, might result in less adaptable athletes and burn-out as a consequence of early specialisation (Mostafavifar et al., 2014).

This twin-track approach to generic and specific development, presented in this thesis seemingly aligns with later specialisation (Moesch et al., 2011). The benefits of the involvement in a broader range of sports or PA and specialising later in a single sport have previously been reported. Santos et al. (2017) stated that "diversification may lead to several advantages in later sport performance" (p. 1766) and that sport specific performance is enhanced by sustained PL. Therefore the nurturing of FMS over a sustained period, supporting improved adaptability and transference of skills (Giblin et al., 2014) is concomitant with developing and maintaining a proficient GMA base as evidenced in this thesis.

Though the historical precedent for GMA is evident, encouraging the outlined use of generic agility training in performance athletes remains a challenge for those involved in AD. However, Landow (2018) recently condoned the application of a generalist model to movement. Advocating the underpinning of generalist proficiencies in the context of developing specific multidirectional skills, from an athlete's and a coach's perspective. Despite retaining a more constrained interpretation of agility Landow seemingly relates the development of fundamental and foundational movement skills to support the development of specific agile movements, and thereby indicates the contemporary and inconclusive nature of the GMA debate. Following up on the point made in Chapter Four (see Sections 4.1.1 and 4.4.2) the relationship between specific and general ability, the role of GMA, and any corresponding training focus may be a matter of perspective. For example in contemporary resistance training the popular use of complex and contrast training (Hammami et al., 2017), i.e., the combinations of high and low loading weight training within sessions or high loading weight training with plyometric and speed exercises, have become established. However, this type of resistance training may be perceived from a generalist perspective as promoting broader combinations of generic neuromuscular attributes.

7.1.1 Implications for GMA in AD.

There are a number of implications for applied coaching practice in AD which can be highlighted. Each is based on the findings within this thesis and are discussed in the following section.

Applying the new agility construct.

In redefining agility in this thesis there is the opportunity for coaches to use the term in a less restrictive manner. Although defining and interpreting agility remains problematic there has been a consensus amongst practitioners as to how agility is perceived (Nimphius et al., 2018). This new agility construct stands in contrast to perceiving agility as an ability that relates to specific types of movements such as the

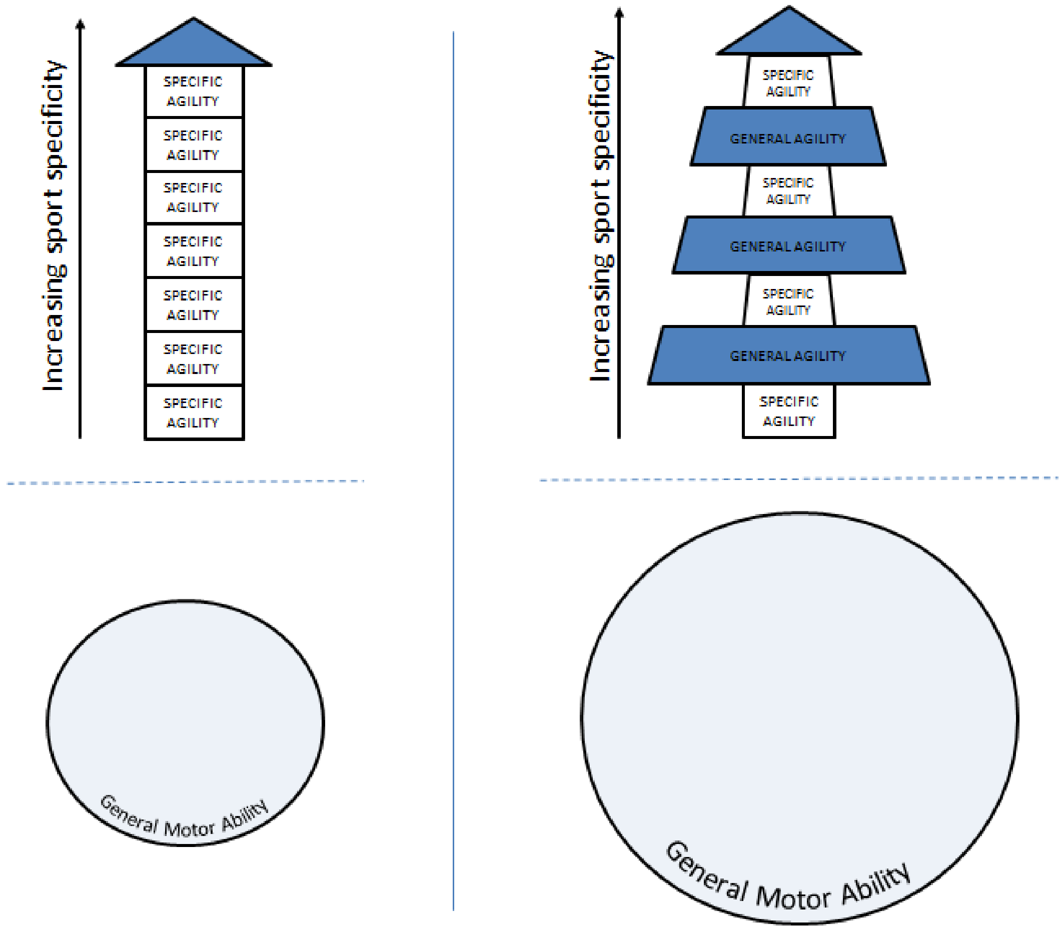

Figure 7.1. A larger base of GMA, operationalised through blending generic and specific agility may support improved sport-specific performance, facilitate skill transfer and improve athlete robustness.

ability to change direction whether this is under preplanned or reactive condition[2]. Agility should be interpreted as generic agility which is comprised of collective movement competencies that provide foundational support for the development of specific agility, those context-specific movement complexes required for specific performance outcomes: for example, a triple jump in athletics or a round off flick in gymnastics. The implication for coaches here lies in the proposal that agility should be

[2]It should be noted that the tests for generic and specific agility used in Chapter Four did employ preplanned and reactive CoD tasks. However the decision to use such movements reflected an opportunity to assess general and specific abilities familiarly and straightforwardly for the participants in this study, rather than being expansive examples of both generic and specific agility.

thought of as an overarching construct rather than a specific type or domain of movement. Generic and specific agility become classifications of movements that are executable in various contexts, generic agility shapes and develops FMS and components of physical fitness. While specific agility forms the functional movements required in context-specific situations to solve exact movement challenges, which are diverse, situational and dependent on the task at hand. The challenge for coaches and practitioners in applying this broader agility construct is reflected in their willingness to recognise and appreciate the potential of generic agility development to enhance context-specific practice.

Chapter Three and Four were able to provide evidence as to how GMA may well align with measures of both generic and specific motor abilities. The potential for GMA was shown to predict performance in these general and more sport-specific movements. This credible predictive ability has clear implications for the possible practice of assessing GMA in AD programmes. Two potential benefits include GMA testing as an assessment of athletic giftedness and using GMA in efficient motor skill development.

Testing for GMA in assessing athletic giftedness.

The historical context of GMA testing covered in Chapter Three highlighted the central role GMA testing previously held. With the advent of research proposing that specificity in the assessment of targeted neuromuscular abilities was more appropriate for assessing athlete progression or athletic potential through identifying sport specific qualities (see Section Chapter Three), GMA testing in performance environments has declined. The evidence here advocates that recognising a player's GMA ability through testing has the potential to support the talent identification process. While not replacing sport-specific tests, complementary measurement of general movement competences would form a dominant element in assessing an athlete's potential and current status.

The implication for coaching and performance staff is that a composite assessment of generalised motor tasks may summarise their athletes' current status or provide guidance in the identification of athletic potential, without the need for focusing on multiple forms of highly specialised movement tests. This may be particularly relevant when considering the age of peak competitive performance in athletes (Allen & Hopkins, 2015), as the identification of appropriate attributes required for elite performance have been shown to vary with specific attributes and different sports. For example those sporting activities requiring more complex coordination and dynamic sequencing peak at a higher age (Hollings, Hopkins, & Hume, 2014). Therefore, assessing generic attributes may avoid the issues relating to the importance of timing and specificity but still provide valuable information on athletic potential.

The efficiency in the transfer of motor competence.

The findings in Chapter Five proposed that performers with better GMA could outperform performers with lower GMA when challenged with a novel movement task. Whether this is a direct transfer of motor competence from one skill to another or the benefit gained from having more thoroughly developed motor maps is yet to be determined. If, as speculated, these better GMA performers can capitalise on their more extensive and better-maintained repertoire of FMS and associated neuromuscular attributes to support the learning and re-learning of motor skills, this has wide-reaching implications for motor skill development. It suggests that AD programmes that train common and shared motor competencies can facilitate the re-learning of movement patterns in injury rehabilitation or enhance the options in a producing a movement solution to decrease the monotony of specific tissue loading (degeneracy), both of which help improve the robustness of a performer. Further research to identify how GMA might support this transfer of skill and increase in resilience may include examining the relationship in GMA and sport specific competency in a broader range of sports performers, or retrospective studies on occurrence of injury and GMA (see Section 7.3).

Such programmes have advantages for a number of stakeholders in the AD process (a) coaches are supplied with performers who are coachable i.e., they have the pre-requisite motor competencies, physical attribute and characteristics to maximise their potential of technical and tactical development (MacNamara & Collins, 2011) (b) systems are supplied with athletes that are worth investing in, who have the capacity to progress and very importantly not *burn out* (c) medical staff work with individuals who have greater resilience and are therefore more likely to be available for selection.

Finally, in Chapter Five, it was noted that generic agility could be aligned with the concept of PL, promoting the development of motor competence to encourage and support lifelong engagement in PA. While not directly implicated in a performance environment this has long-term relevance for maintaining personal health and wellbeing.

PL in adults

The concept of developing motor competency and motor confidence in supporting engagement in PA in younger individuals is well established. However, the use of PL in an adult population to promote PA is still developing (Jones et al., 2018). The role that generic agility might play in developing and supporting motor competence in all levels and ages of performers should be acknowledged, whether this is the development of generic movement skill that allows a youth athlete to integrate complex skills to improve competitive performance or enables an adult to participate in a health-related exercise. Therefore, the implied benefits of utilising generic agility and improving GMA should encourage coaches, teachers and health-related exercise practitioners to capitalise on its inclusion in sport and exercise programmes.

CoD mechanics

CoD mechanics are becoming better understood, with more literature explicitly examining the performance aspect (Young, Miller, & Talpey, 2015). Maintaining high CoM velocity in CoD movements with smaller CoD angles (45°) and achieving higher peak velocity (e.g., acceleration over a short distance; Little & Williams, 2005) and better deceleration into large CoD angles (180°) are the suggested outcomes in this thesis which support previous findings and provide insight for the coaching of these movements (see section 4.1.4). These findings may well guide the strength development and conditioning of athletes undertaking these type of movements. Particularly the current focus on eccentric neuromuscular capabilities to support loading in deceleration (Harper et al., 2018). Despite the identification of specific mechanical factors which relate to CoD_{pp} and CoD_r and a more complex and novel CoD task, the potential importance of MV in the technical production of appropriate movement solutions is acknowledged in this thesis (see Section 4.1.5). That is, the transfer and application of generic experiences to allow variation in specific outcomes thereby accommodating perturbations or providing flexibility and options in the way a motoric challenge is overcome.

7.2 Limitations

This thesis aimed to provide a fair and objective assessment of the role of GMA, generic and specific agility in developing athletes. The use of correlations coefficients through to complex multilevel modelling ensured that a thorough and appropriate range of statistical assessments were undertaken to provide empirical evidence for the application of these three constructs in AD. It is implied within each research design that the selected analytical techniques provided clear and objective evidence for the use of GMA assessment in the development of athletes. However, not using a control group in the study presented in Chapter Five may limit the ability to generalise the findings of this investigation. A control group would have allowed for the direct comparison of the longitudinal impact of GMA on the intervention groups and a non-intervention group. The relatively low participant numbers in the kinematic analysis in Chapter Four might also have been an issue relating to interpretation and generalisability of findings. The challenge of utilising an experimental control group which would not have been affected by growth or maturation would have been difficult, especially over an extended intervention period. The compromise of comparing groups which were undertaking different development programmes which enabled comparison of GMA development occurred. This approach was deemed an appropriate research design to mediate the necessity of undertaking the comparison while not having an actual control. Regarding low participant numbers, this will impact the power of statistical measures, and it is therefore recognised that caution is needed in generalising the results from the kinematic analysis in Chapter Four. As previously acknowledged (see section 3.4.1) repeating multiple correlation on the same data set increases the chance of type 1 errors when interpreting coefficients, this can be seen as a limitation in the research design of the comparative studies in this thesis.

An issue related to the study in Chapter Six concerns the design and components of the novel task. It is debatable as to whether this task was too similar to a generic multiple CoD task, which may lack a degree of ecological validity (Nimphius et al., 2018). The balance between designing a complex movement incorporating specific movement patterns as well as having the ability to measure performance, alongside creating an authentic movement objectively, is challenging. Compromises between these factors ensured the novel task was objective, authentic and sufficiently novel and complex.

7.3 Recommendations for Future Studies

Further investigation into the benefits of training GMA and its longitudinal effect may help support its re-inclusion in AD programmes and its use by coaches to inform their training strategy. In addition, the empirical exploration of GMA's place in supporting the learning and re-learning of skilled performance would also prove valuable, mainly from a rehabilitation context. Therefore, some suggestions for further study are presented in this final section.

The mechanics associated with generic agility are not perhaps as well understood as they are for more specific movement outcomes. Therefore, there is a need for further investigation into the kinematics and kinetics of a greater range of generic movements or FMS which support sport-specific movements. Although this is not necessarily a search for an optimised technique in these movements, it is essential to understand the mechanical aspects of these movements. As suggested in this thesis the ability to vary movement solutions has many significant benefits; investigating or confirming this through such mechanical analysis is important.

The use of FMS training and NMT were covered in Chapter Five, however further exploration of the training modalities capable of developing and maintaining generic and specific agility should be considered in the future. It is also clear that the operationalisation of GMA requires investigation; that is the assessment of GMA and the effect of generic and specific agility training. Investigating the nature of adaptation from varying and distinct FMS and NMT would help target the most productive and efficient manner in which to operationalise generic agility training.

It is proposed in this thesis that increased robustness is a concomitant of improving GMA. The proposed mechanisms have been discussed as to how developing better generic agility would potentially lower injury risk (Sugimoto et al., 2017). Consequently, evaluating the link between the level of GMA and injury rates would provide a more accurate insight into the resilience of an athlete and the link with GMA.

It has been suggested in this thesis that engaging in generic movements such as developing FMS requires the extensive and challenging use of the neuromuscular system. Investigations examining muscular activation and neural stimulation using imaging techniques or electromyography, alternatively assessing local control mechanisms and their influence on the neuromuscular system are reasonable suggestions for future research. However, there remains ethical challenges in the application of such research in a broader human population as currently most evidence for such adaptations are centred on non-human based mammals.

The longitudinal investigation in Chapter Five highlighted how GMA could develop over time, regardless of the specific nature of the PA programme in which the individuals were engaged. Chronological age or maturational state was not assessed in this study, however. Therefore, further investigation into the long-term effect of developing GMA should take into account these growth and maturational factors. For example, the effect of peak height velocity and the change in physical attributes, this specifically relates to pre, circa and post the peak height velocity phases in an individual's development (Read et al., 2018). It should also be noted that this thesis was delimited to examining the role of GMA, except for the brief discussion of the practical implementation of generic agility training in Chapter Five. Therefore, it is recommended that further research into the programming, protocols and delivery of developing generic agility should be take place, reviewing the strategy of implementing generic agility training.

The flexibility in providing different movement solutions to specific challenges has been proposed as a distinct benefit of a good GMA base (see Chapter Four). Further study helping advance our understanding of how neural mechanisms support this variability should be undertaken. The investigation into the identification of active neural networks involved in generic and specific agility tasks may offer an insight into the neuromuscular solutions employed in producing specific movement outcomes. Of particular importance is the concept of motor modules and how this proposed unitising of activation patterns may support adaptability in coordinating motor control and facilitate skill learning (Hirano & Funase, 2017).

Finally, the role of GMA in influencing or modifying behaviours is an intriguing theoretical area. Chapter Three demonstrated that specific characteristics of players correlated to a measure of GMA. These characteristics may be seen to be reflective of an individual's behaviour in a particular environment. Further study into the association between the changes in behavioural characteristics and the development and maintenance of generic agility would be of interest. Carling and Collins (2014) previously commented on the need to include assessments which better characterised prerequisites for future success. The investigation into the role of GMA reflecting a broad range of prerequisites, including behavioural characteristics, for the identification of giftedness should be undertaken in the future.

References

Abbott, A., Collins, D., Sowerby, K. & Martindale, R. (2007). *Developing the Potential of Young People in Sport*: A Report for Sportscotland by the University of Edinburgh. Edinburgh: Sport Scotland

Ali, A., Pigou, D., Clarke, L., & McLachlan, C. (2017). Literature review on motor skill and physical activity in preschool children in new zealand. *Advances in Physical Education*, *07*(01), 10–26. https://doi.org/10.4236/ape.2017.71002

Allen, S. V., & Hopkins, W. G. (2015). Age of peak competitive performance of elite athletes: A systematic review. *Sports Medicine*, *45*(10), 1431–1441. https://doi.org/10.1007/s40279-015-0354-3

Andriyanova, E. Y., & Lanskaia, O. V. (2014). Functional plasticity of spinal circuits in long-term sports activity adaptation. *Human Physiology*, *40*(3), 299–309. https://doi.org/10.1134/S0362119714030025

Arata, A. (1999). *Kinematic comparison of high speed backward and forward running*. (Doctoral dissertation) University of Oregon. Eugene, OR. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a366361.pdf

Archer, D. T., Drysdale, K., & Bradley, E. J. (2016). Differentiating technical skill and motor abilities in selected and non-selected 3-5 year old team-sports players. *Human Movement Science*, *47*, 81–87. https://doi.org/10.1016/j.humov.2016.02.001

Arshi, A. R., Nabavi, H., Mehdizadeh, S., & Davids, K. (2015). An alternative approach to describing agility in sports through establishment of a relationship between velocity and radius of curvature. *Journal of Sports Sciences, 33*(13), 1349–1355. https://doi.org/10.1080/02640414.201 4.990481

Avanzino, L., Pelosin, E., Abbruzzese, G., Bassolino, M., Pozzo, T., & Bove, M. (2014). Shaping motor cortex plasticity through proprioception. *Cerebral Cortex*, *24*(10), 2807–2814. https://doi.org/10.1093/cercor/bht139

Bailey, R., Collins, D., Ford, P., MacNamara, Á., Toms, M. & Pearce, G. (2010). *Participant development in sport: An academic review*. Leeds, UK: sports coach UK

Bailey, R., & Collins, D. (2013). The standard model of talent development and its discontents. *Kinesiology Review*, *2*(4), 248–259. https://doi.org/10.1123/krj.2.4.248

Baker, J., Cote, 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. https://doi.org/10.1080/10413200305400

Baker, J., & Horton, S. (2004). A review of primary and secondary influences on sport expertise. *High Ability Studies*, *15*(2), 211–228. https://doi.org/10.1080/1359813042000314781

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. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/24616603

Baker, D. G., & Newton, R. U. (2006). Discriminative analyses of various upper body tests in professional rugby-league players. *International Journal of Sports Physiology and Performance*, *1*(4), 347–360. https://doi.org/10.1123/ijspp.1.4.347

Baker, D., Wilson, G., & Carlyon, B. (1994). Generality versus specificity: A comparison of dynamic and isometric measures of strength and speed-strength. *European Journal of Applied Physiology and Occupational Physiology*, *68*(4), 350–355. https://doi.org/10.1007/BF00571456

Balyi, I. & Hamilton, A. (2004). Long-term athlete development: trainability in childhood and adolescence. Windows of opportunity. Optimal trainability. Victoria: National Coaching Institute British Columbia & Advanced Training and Performance Ltd, p.194. 4.

Barnes, C., Archer, D. T., Hogg, B., Bush, M., & Bradley, P. S. (2014). The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine*, *35*(13), 1095–1100

Barnett, L. M., Lai, S. K., Veldman, S. L. C., Hardy, L. L., Cliff, D. P., Morgan, P. J., … Okely, A. D. (2016). Correlates of gross motor competence in children and adolescents: A systematic review and meta-analysis. *Sports Medicine*, *46*(11), 1663–1688. https://doi.org/10.1007/s40279-016-0495-z

Barnett, M. L., Ross, D., Schmidt, R. A., & Todd, B. (1973). Motor skills learning and the specificity of training principle. *Research Quarterly of the American Association for Health, Physical Education and Recreation*, *44*(4), 440–447. https://doi.org/10.1080/10671188.1973.10615224

Barnett, L. M., Stodden, D., Cohen, K. E., Smith, J. J., Lubans, D. R., Lenoir, M., … Morgan, P. J. (2016). Fundamental movement skills: An important focus. *Journal of Teaching in Physical Education*, *35*(3), 219–225. https://doi.org/10.1123/jtpe.2014-0209

Barnett, L. M., van Beurden, E., Morgan, P. J., Brooks, L. O., & Beard, J. R. (2010). Gender Differences in Motor Skill Proficiency From Childhood to Adolescence. *Research Quarterly for Exercise and Sport*, *81*(2), 162–170. https://doi.org/10.1080/02701367.2010.10599663

Barros, J. D. S. V., Lima, M. V. M. de, Sampaio, A. N., Rocha, S. M. B. de M., Dantas, P. M. S., Batista, S. R. D. A., & Silva, R. P. M. (2017). Analysis of motor capacities in the maturational stages of female adolescents. *Journal of Human Growth and Development*, *27*(2), 206-212. https://doi.org/10.7322/jhgd.125018

Baumgartner, T. A., & Zuidema, M. A. (1972). Factor analysis of physical fitness tests. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *43*(4), 443–450. https://doi.org/10.1080/10671188.1972.10615157

Bell, D. R., Post, E. G., Trigsted, S. M., Hetzel, S., McGuine, T. A., & Brooks, M. A. (2016). Prevalence of sport specialization in high school athletics: A 1-year observational study. *The American Journal of Sports Medicine*, *44*(6), 1469–1474. https://doi.org/10.1177/0363546516629943

Benvenuti, C., Minganti, C., Condello, G., Capranica, L., & Tessitore, A. (2010). Agility assessment in female futsal and soccer players. *Medicina (Kaunas, Lithuania)*, *46*(6), 415–20. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20944450

Bernstein, N.A. (1967). *The Control and Regulation of Movements*. London: Pergamon Press.

Berry, J., Abernethy, B., & Côté, J. (2008). The contribution of structured activity and deliberate play to the development of expert perceptual and decision-making skill. *Journal of Sport & Exercise Psychology*, *30*(6), 685–708. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19164836

Bickel, R. (2007). *Multilevel analysis for applied research: It's just regression!*. New York: Guilford Press.

Bissas, A. I., Cooke, C. B., Paradisis, G. P., & Liefeith, A. K. (1996). The stretch-shortening cycle and sprinting performance. *Journal of Sports Sciences*, 14(1), 4-5.

Bloomfield, J., Polman, R., Donoghue, P. O., & Mcnaughton, L. (2007). Dynamic type sports. *Journal of Strength and Conditioning Research*, *21*(4), 1093–1100.

Booth, M. A., & Orr, R. (2016). Effects of plyometric training on sports performance. *Strength and Conditioning Journal*, *38*(1), 30–37. https://doi.org/10.1519/SSC.0000000000000183

Bosch, F. (2010). *Strength training and coordination: An integrative approach*. Rotterdam, Netherlands: 2010 Uitgevers

Bosch, F. (2014, October). *Motor control: Central control v decentralised control*. Lecture presented at United Kingdom Strength and Conditioning Association workshop. UK

Bradshaw, R. J., Young, W. B., Russell, A., & Burge, P. (2011). Comparison of offensive agility techniques in Australian Rules football. *Journal of Science and Medicine in Sport*, *14*(1), 65–69. https://doi.org/10.1016/j.jsams.2010.06.002

Bronner, S., Ojofeitimi, S., & Rose, D. (2003). Injuries in a modern dance company: effect of comprehensive management on injury incidence and time loss. *The American Journal of Sports Medicine*, *31*(3), 365–373. https://doi.org/10.1177/03635465030310030701

Browne, J. (2009). Motor Control In Sprinting. *Track Coach*, 6111–6114.

Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport. *Sports Medicine*, *38*(12), 1045–1063. https://doi.org/10.2165/00007256-200838120-00007

Bruininks, R. H. (1978). Bruininks-Oseretsky *Test of Motor Proficiency*. Circle Pines, Minnesota: American Guidance Service.

Bruininks, R. H., & Bruininks, B. D. (2005). *Bruininks-Oseretsky Test of Motor Proficiency* (2nd Ed.) (BOT-2). Minneapolis, MN: Pearson Assessment

Burton, A. W., & Miller, D. E. (1998). *Movement skill assessment*. Champaign, IL: Human Kinetics.

Burns, R. D., Fu, Y., Fang, Y., Hannon, J. C., & Brusseau, T. A. (2017). Effect of a 12-week physical activity program on gross motor skills in children. *Perceptual and Motor Skills*, *124*(6), 1121–1133. https://doi.org/10.1177/0031512517720566

Burton, A. W., & Miller, D. E. (1998). *Movement skill assessment*. Champaign, IL: Human Kinetics.

Burton, A. W., & Rodgerson, R. W. (2001). New perspectives on the assessment of movement skills and motor abilities. *Adapted Physical Activity Quarterly, 18,* 347–365.

Buttifant, D., Graham, K. and Cross, K. (1999) Agility and speed of soccer players are two different performance parameter. *Journal of Sports Science* 17, 809.

Calhoon, G. & Fry, A. C. (1999). Injury rates and profiles of elite competitive weightlifters. *Journal of AthleticTraining, 34*, 232–238.

Campbell, W. R., & Tucker, N. M. (1967). *An introduction to tests and measurement in physical education*. London, UK: G. Bell & Sons.

Capistrano, R., Ferrari, E. P., Alexandre, J. M., Silva, R. C. da, Cardoso, F. L., & Beltrame, T. S. (2016). Relation between motor perfomance and physical fitness level of schoolchildren. *Journal of Human Growth and Development*, *26*(2), 174-180. https://doi.org/10.7322/jhgd.119261

Carling, C., & Collins, D. (2014). Comment on “Football-specific fitness testing: adding value or confirming the evidence?” *Journal of Sports Sciences, 32*(13), 1206–1208. https://doi.org/10.1080/02640414.2014.898858

Carlon, T. (2012). The importance of perceptual and decision making factors of agility performances in open skilled sports: A review of literature. *Journal of Australian Strength & Conditioning*. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=84427861&site=ehost-live

Carson, H. J., & Collins, D. (2015). Tracking technical refinement in elite performers: The good, the better, and the ugly. *International Journal of Golf Science*, *4*(1), 67–87. https://doi.org/dx.doi.org/10.1123/ijgs.2015-0003

Carson, H. J., Collins, D., & Richards, J. (2014). Intra-individual movement variability during skill transitions: A useful marker? *European Journal of Sport Science*, *14*(4), 327–336. https://doi.org/10.1080/17461391.2013.814714

Cazzola, D., Pavei, G., & Preatoni, E. (2016). Can coordination variability identify performance factors and skill level in competitive sport? The case of race walking. *Journal of Sport and Health Science*, *5*(1), 35–43. https://doi.org/10.1016/j.jshs.2015.11.005

Chaabene, H., Prieske, O., Negra, Y., & Granacher, U. (2018). Change of direction speed: toward a strength training approach with accentuated eccentric muscle actions. *Sports Medicine*, *48*(8), 1773–1779. https://doi.org/10.1007/s40279-018-0907-3

Chaalali, A., Rouissi, M., Chtara, M., Owen, A., Bragazzi, N. L., Moalla, W., … Chamari, K. (2016). Agility training in young elite soccer players: Promising results compared to change of direction drills. *Biology of Sport*, *33*(4), 345–351. https://doi.org/10.5604/20831862.1217924

Chaiken, S. R., Kyllonen, P. C., & Tirre, W. C. (2000). Organization and components of psychomotor ability. *Cognitive Psychology*, *40*(3), 198–226. https://doi.org/10.1006/cogp.1999.0729

Chaouachi, A., Chtara, M., Hammami, R., Chtara, H., Turki, O., & Castagna, C. (2014). Multidirectional sprints and small-sided games training effect on agility and change of direction abilities in youth soccer. *Journal of Strength and Conditioning Research*, *28*(11), 3121–3127. https://doi.org/10.1519/JSC.0000000000000505

Chelladurai, P. (1976). Manifestations of agility. *Canadian Association of Health, Physical Education, and Recreation* 42, 36–41.

Chen, W., Hammond-Bennett, A., & Hypnar, A. (2017). Examination of motor skill competency in students: evidence-based physical education curriculum. *BMC Public Health*, *17*(1), 222. https://doi.org/10.1186/s12889-017-4105-2

Christianson, P., & Deutsch, J. (2012). Making a case for early sport specialization in youth athletes. *Journal of Youth Sports*, *6*(2), 3–7.

Cissik, J., & Barnes, M. (2004). Sport speed and agility. Minterey, CA: Coaches Choice

Clark, C. C. T., Barnes, C. M., Holton, M., Summers, H. D., & Stratton, G. (2016). A Kinematic Analysis of Fundamental Movement Skills. *Sport Science Review*, *25*(3–4), 261–275. https://doi.org/10.1515/ssr-2016-0014

Clark, J. E., & Metcalfe, J. S. (2002). The mountain of motor development: A metaphor. In J. E. Clark & J. H. Humphrey (Eds.), *Motor development: Research and reviews* (Vol. 2, pp. 163–190). Reston, VA: National Association of Sport and Physical Education.

Čoh, M., Vodičar, J., Žvan, M., Šimenko, J., Stodolka, J., Rauter, S., & Maćkala, K. (2018). Are change-of-direction speed and reactive agility independent skills even when using the same movement pattern? *Journal of Strength and Conditioning Research*, *32*(7), 1929–1936. https://doi.org/10.1519/JSC.0000000000002553

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–9.

Collins, D. J., Macnamara, Á., & McCarthy, N. (2016a). Putting the bumps in the rocky road: optimizing the pathway to excellence. *Frontiers in Psychology*, *7*(SEP), 1–6. https://doi.org/10.3389/fpsyg.2016.01482

Collins, D., MacNamara, Á., & McCarthy, N. (2016b). Super champions, champions, and almosts: Important differences and commonalities on the rocky road. *Frontiers in Psychology*, *6*(JAN), 1–11. https://doi.org/10.3389/fpsyg.2015.02009

Collins, D., &. MacNamara, Á. (2018) *Talent Development A practitioner Guide*. Oxon, UK: Routledge

Collins, D., Bailey, R., Ford, P. A., MacNamara, Á., Toms, M., & Pearce, G. (2012). Three Worlds: New directions in participant development in sport and physical activity. *Sport, Education and Society*, *17*(2), 225–243. https://doi.org/10.1080/13573322.2011.607951

Comfort, P., Graham-Smith, P., Matthews, M. J., & Bamber, C. (2011). strength and power characteristics in english elite rugby league players. *Journal of Strength and Conditioning Research*, *25*(5), 1374–1384. https://doi.org/10.1519/JSC.0b013e3181d687f5

Condello, G., Kernozek, T. W., Tessitore, A., & Foster, C. (2016). Biomechanical analysis of a change-of-direction task in college soccer players. *International Journal of Sports Physiology and Performance*, *11*(1), 96–101. https://doi.org/10.1123/ijspp.2014-0458

Coq, J. O., & Barbe, M. F. (2011). Peripheral and central changes combined induce movement disorders on the basis of disuse or overuse. in B. J. Larsen. Hauppauge (Ed.), *Movement Disorders: Causes, Diagnoses and Treatments (pp. 2-14)*. NY: Nova Science Publishers Inc.

Costello, F., & Kreis E. J. (1993) *Sports Agility*. Nashville, TN: Taylor Sports

Côté, J. (1999). The influence of the family in the development of talent in sport. *The Sport Psychologist*, *13*(4), 395–417. https://doi.org/10.1123/tsp.13.4.395

Côté, J., Lidor, R., & Hackfort, D. (2009). ISSP position stand: To sample or to specialize? Seven postulates about youth sport activities that lead to continued participation and elite performance. *International Journal of Sport and Exercise Psychology*, *7*(1), 7–17. https://doi.org/10.1080/1612197X.2009.9671889

Coull, J., Tremblay, L., & Elliott, D. (2001). Examining the specificity of practice hypothesis: Is learning modality specific? *Research Quarterly for Exercise and Sport*, *72*(4), 345–354. https://doi.org/10.1080/02701367.2001.10608971

Cozens, F. W. (1928). The measurement of general athletic ability in college men. *American Physical Education Review*, *33*(10), 634–638.

Cumming, S. P., Lloyd, R. S., Oliver, J. L., Eisenmann, J. C., & Malina, R. M. (2017). Bio-banding in sport. *Strength and Conditioning Journal*, *39*(2), 34–47. https://doi.org/10.1519/SSC.0000000000000281

Davids, K., Lees, A., & Burwitz, L. (2000). Understanding and measuring coordination and control in kicking skills in soccer: Implications for talent identification and skill acquisition. *Journal of Sports Sciences*, *18*, 703–714. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/02640410050120087

Davies, M. J., Young, W., Farrow, D., & Bahnert, A. (2013). Comparison of agility demands of small-sided games in elite Australian football. *International Journal of Sports Physiology and Performance*, *8*(2), 139–147.

Delextrat, A., Grosgeorge, B., & Bieuzen, F. (2015). Determinants of Performance in a New Test of Planned Agility for Young Elite Basketball Players. *International Journal of Sports Physiology and Performance*, *10*(2), 160–165. https://doi.org/10.1123/ijspp.2014-0097

DeWeese, B., & Nimphius, S. (2016). Speed and agility program design and technique. In N. Triplett & G. Haff (Eds.), *Essentials of Strength and Conditioning* (pp. 521–557). Champaign, IL: Human Kinetics.

Dick, F. W. (2014). *Sports Training Principles: An Introduction to Sports Science*. London, Uk: Bloomsbury Publishing, ProQuest Ebook Central. Retrieved from https://ebookcentral-proquest-com.yorksj.idm.oclc.org/lib/yorksj/detail.action?docID=4636453.

Diedrichsen, J., & Kornysheva, K. (2015). Motor skill learning between selection and execution. *Trends in Cognitive Sciences*, *19*(4), 227–233. https://doi.org/10.1016/j.tics.2015.02.003

DiFiori, J. P., Benjamin, H. J., Brenner, J. S., Gregory, A., Jayanthi, N., Landry, G. L., & Luke, A. (2014). Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. *British Journal of Sports Medicine*, *48*(4), 287–288. https://doi.org/10.1136/bjsports-2013-093299

Dingwell, J. B., Cusumano, J. P., Cavanagh, P. R., & Sternad, D. (2001). Local dynamic stability versus kinematic variability of continuous overground and treadmill walking. *Journal of Biomechanical Engineering*, *123*(1), 27. https://doi.org/10.1115/1.1336798

Dos'Santos, T., Thomas, C., Comfort, P., & Jones, P. A. (2018). The effect of angle and velocity on change of direction biomechanics: An angle-velocity trade-off. *Sports Medicine*, (0123456789). https://doi.org/10.1007/s40279-018-0968-3

Dos'Santos, T., Thomas, C., Jones, P. A., & Comfort, P. (2017). Mechanical determinants of faster change of direction speed performance in male athletes. *Journal of Strength and Conditioning Research*, *31*(3), 696–705. https://doi.org/10.1519/JSC.0000000000001535

Drost, D. K., & Todorovich, J. R. (2013). Enhancing Cognitive Understanding to Improve Fundamental Movement Skills. *Journal of Physical Education, Recreation & Dance*, *84*(4), 54–59. https://doi.org/10.1080/07303084.2013.773838

Drowatzky, J. N., & Zuccato, F. C. (1967). Interrelationships between selected measures of static and dynamic balance. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *38*(3), 509–510. https://doi.org/10.1080/10671188.1967.10613424

Dubravcic-Simunjak, S., Pecina, M., Kuipers, H., Moran, J., & Haspl, M. (2003). The incidence of injuries in elite junior figure skaters. *The American Journal of Sports Medicine*, *31*(4), 511–517. https://doi.org/10.1177/03635465030310040601

Edelman, G. M., & Gally, J. A. (2001). Degeneracy and complexity in biological systems. *Proceedings of the National Academy of Sciences*, *98*(24), 13763–13768. https://doi.org/10.1073/pnas.231499798

Edgerton, V. R., & Roy, R. R. (2009). Robotic training and spinal cord plasticity. *Brain Research Bulletin*, *78*(1), 4–12. https://doi.org/10.1016/j.brainresbull.2008.09.018

Edwards, L. C., Bryant, A. S., Keegan, R. J., Morgan, K., Cooper, S.-M., & Jones, A. M. (2018). 'Measuring' physical literacy and related constructs: A systematic review of empirical findings. *Sports Medicine*, *48*(3), 659–682. https://doi.org/10.1007/s40279-017-0817-9

Elbert, T., & Rockstroh, B. (2004). Reorganization of human cerebral cortex: The range of changes following use and injury. *The Neuroscientist*, *10*(2), 129–141. https://doi.org/10.1177/1073858403262111

Ellison, P., Kearney, P., Sparks, S., Murphy, P., & Marchant, D. (2017). Further evidence against eye–hand coordination as a general ability. *International Journal of Sports Science & Coaching*, *0*(0), 174795411774713. https://doi.org/10.1177/1747954117747132

Engineer, N. D., Engineer, C. T., Reed, A. C., Pandya, P. K., Jakkamsetti, V., Moucha, R., & Kilgard, M. P. (2012). Inverted-U function relating cortical plasticity and task difficulty. *Neuroscience*, *205*, 81–90. https://doi.org/10.1016/j.neuroscience.2011.12.056

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*(3), 363–406. https://doi.org/10.1037/0033-295X.100.3.363

Ericsson, K. A., Roring, R. W., & Nandagopal, K. (2007). Giftedness and evidence for reproducibly superior performance: an account based on the expert performance framework. *High Ability Studies*, *18*(1), 3–56. https://doi.org/10.1080/13598130701350593

ESP (2010) Retrieved from https://www.espplay.co.uk/

Faigenbaum, A. D., Lloyd, R. S., MacDonald, J., & Myer, G. D. (2016). Citius, Altius, Fortius : Beneficial effects of resistance training for young athletes: Narrative review. *British Journal of Sports Medicine*, *50*(1), 3–7. https://doi.org/10.1136/bjsports-2015-094621

Farrow, D., Young, W., & Bruce, L. (2005). The development of a test of reactive agility for netball: a new methodology. *Journal of Science and Medicine in Sport*, *8*(1), 52–60. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15887901

Favazza, P. C., Siperstein, G. N., Zeisel, S. A., Odom, S. L., Sideris, J. H., & Moskowitz, A. L. (2013). Young athletes program: impact on motor development. *Adapted Physical Activity Quarterly*, *30*(3), 235–253. https://doi.org/10.1123/apaq.30.3.235

Favor, J. K. (2011). The relationship between personality traits and coachability in ncaa divisions i and ii female softball athletes. *International Journal of Sports Science & Coaching*, *6*(2), 301–314. https://doi.org/10.1260/1747-9541.6.2.301

Field, A. P. (2009). *Discovering Statistics Using SPSS: and Sex and Drugs and Rock 'n' Roll* (3rd Ed.). London: Sage publications.

Fiorilli, G., Iuliano, E., Mitrotasios, M., Pistone, E. M., Aquino, G., Calcagno, G., & di Cagno, A. (2017). Are change of direction speed and reactive agility useful for determining the optimal field position for young soccer players? *Journal of Sports Science & Medicine*, *16*(2), 247–253. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/28630578

Fleishman, E. A. (1958a). An analysis of positioning movements and static reactions ’. *Journal of Experimental Psychology*, *55*(1), 13–24.

Fleishman, E. A. (1958b). Dimensional analysis of movement reactions. *Journal of Experimental Psychology*, *55*(5), 438–453. https://doi.org/10.1037/h0040511

Fleishman, E. A. (1964). *The structure and measurement of physical fitness*. Englewood Cliffs, NJ: Prentice Hall.

Fleishman, E. A. (1972). On the relation between abilities, learning, and human performance. *American Psychologist*, *27*(11), 1017–1032. https://doi.org/10.1037/h0033881

Ford, P. R., Ward, P., Hodges, N. J., & Williams, A. M. (2009). The role of deliberate practice and play in career progression in sport: The early engagement hypothesis. *High Ability Studies*, *20*(1), 65–75. https://doi.org/10.1080/13598130902860721

Ford, P., De Ste Croix, M., Lloyd, R., Meyers, R., Moosavi, M., Oliver, J., … Williams, C. (2011). The Long-Term Athlete Development model: Physiological evidence and application. *Journal of Sports Sciences*, *29*(4), 389–402. https://doi.org/10.1080/02640414.2010.536849

Fox, A. S. (2018). Change-of-Direction Biomechanics: Is What’s Best for Anterior Cruciate Ligament Injury Prevention Also Best for Performance? *Sports Medicine*, *48*(8), 1799–1807. https://doi.org/10.1007/s40279-018-0931-3

Francis, C. E., Longmuir, P. E., Boyer, C., Andersen, L. B., Barnes, J. D., Boiarskaia, E., … Tremblay, M. S. (2016). The Canadian Assessment of Physical Literacy: Development of a model of children’s capacity for a healthy, active lifestyle through a delphi process. *Journal of Physical Activity and Health*, *13*(2), 214–222. https://doi.org/10.1123/jpah.2014-0597

Fundamentals of agility (2009). National Coaching Foundation. Electronic resource. English. Published Leeds: Sports Coach UK; Coachwise

Gabbett, T. J. (2002). Physiological characteristics of junior and senior rugby league players. *British Journal of Sports Medicine*, *36*(5), 334–339. https://doi.org/10.1136/bjsm.36.5.334

Gabbett, T., & Benton, D. (2009). Reactive agility of rugby league players. *Journal of Science and Medicine in Sport / Sports Medicine Australia*, *12*(1), 212–4. https://doi.org/10.1016/j.jsams.2007.08.011

Gabbett, T., Georgieff, B., & Domrow, N. (2007). The use of physiological, anthropometric, and skill data to predict selection in a talent-identified junior volleyball squad. *Journal of Sports Sciences*, *25*(12), 1337–1344. https://doi.org/10.1080/02640410601188777

Gabbett, T. J., Jenkins, D. G., & Abernethy, B. (2010). Physiological and anthropometric correlates of tackling ability in junior elite and subelite rugby league players. *Journal of Strength and Conditioning Research*, *24*(11), 2989–2995. https://doi.org/10.1519/JSC.0b013e3181f00d22

Gabbett, T. J., Jenkins, D. G., & Abernethy, B. (2011). Correlates of tackling ability in high- performance Rugby League players. *The Journal of Strength and Conditioning Research*, *25*(1), 72–79. https://doi.org/10.1519/JSC.0b013e3181ff506f

Gabbett, T., Kelly, J., & Pezet, T. (2007). Relationship between physical fitness and playing ability in rugby league players. *The Journal of Strength and Conditioning Research*, *21*(4), 1126-1133. https://doi.org/10.1519/R-20936.1

Gabbett, T., Kelly, J., Ralph, S., & Driscoll, D. (2009). Physiological and anthropometric characteristics of junior elite and sub-elite rugby league players, with special reference to starters and non-starters. *Journal of Science and Medicine in Sport*, *12*(1), 215–222. https://doi.org/10.1016/j.jsams.2007.06.008

Gabbett, T. J., Kelly, J. N., & Sheppard, J. M. (2008). Speed, change of direction speed, and reactive agility of Rrugby League players. *Journal of Strength and Conditioning Research*, *22*(1), 174–181. https://doi.org/10.1519/JSC.0b013e31815ef700

Gabbett, T., & Ryan, P. (2009). Tackling technique, injury risk, and playing performance in high-performance collision sport athletes. *International Journal of Sports Science & Coaching*, *4*(4), 521–533. https://doi.org/10.1260/174795409790291402

Gabbett, T. J., & Seibold, A. J. (2013). Relationship between tests of physical qualities, team selection, and physical match performance in semiprofessional rugby league players. *Journal of Strength and Conditioning Research*, *27*(12), 3259–3265. https://doi.org/10.1519/JSC.0b013e31828d6219

Gagné, R. M. (1965). *The conditions of learning*. New York, New York: Holt, Rinehart & Winston.

Giblin, S., Collins, D., & Button, C. (2014). Physical literacy: Importance, assessment and future directions. *Sports Medicine*, *44*(9), 1177–1184. https://doi.org/10.1007/s40279-014-0205-7

Giblin, S., Collins, D., MacNamara, Á., & Kiely, J. (2014). “Deliberate preparation” as an evidence-based focus for primary physical education. *Quest*, *66*(4), 385–395. https://doi.org/10.1080/00336297.2014.944716

Giboin, L.-S., Gruber, M., & Kramer, A. (2015). Task-specificity of balance training. *Human Movement Science*, *44*, 22–31. https://doi.org/10.1016/j.humov.2015.08.012

Giles, K. (2007). Develop physical competencies: The cornerstone of long term athlete development. Modern Athlete and Coach, 45(1), 8–12.

Giles, K., Penfold, L., & Giorgi, A. (2005). Movement dynamics, long term athlete development: A guide to developing physical qualities in young athletes – An instructional handbook. Australia.

Golby, J., Sheard, M., & Lavallee, D. (2003). A cognitive-behavioural analysis of mental toughness in national rugby league football teams. *Perceptual and Motor Skills*, *96*(2), 455–462.

Goodwin, L. D., & Leech, N. L. (2006). Understanding Correlation: Factors That Affect the Size of r. *The Journal of Experimental Education*, 74(3), 249–266. https://doi.org/10.3200/JEXE.74.3.249-266

Goyakla Apache, R. R. (2005). Activity-based intervention in motor skill development. *Perceptual and Motor Skills*, *100*, 1011–1020.

Graf, C., Koch, B., Falkowski, G., Jouck, S., Christ, H., Stauenmaier, K., … Predel, H.-G. (2005). Effects of a school-based intervention on bmi and motor abilities in childhood. *Journal of Sports Science & Medicine*, *4*(3), 291–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/24453534

Graham, J. F. (2000). Agility training. In L. E. Brown, V. A. Ferrigno, & J. C. Santana (Eds.), *Training for speed, agility and quickness* (1st ed, pp. 81–146). Champaign, IL: Human Kinetics.

Green, B. S., Blake, C., & Caulfield, B. M. (2011a). A valid field test protocol of linear speed and agility in Rugby Union. *Journal of Strength and Conditioning Research*, *25*(5), 1256–1262. https://doi.org/10.1519/JSC.0b013e3181d8598b

Green, B. S., Blake, C., & Caulfield, B. M. (2011b). A comparison of cutting technique performance in rugby union players. *Journal of Strength & Conditioning Research*, *25*(10), 2668–2680. https://doi.org/10.1519/JSC.0b013e318207ed2a

Gulbin, J. P., Croser, M. J., Morley, E. J., & Weissensteiner, J. R. (2013). An integrated framework for the optimisation of sport and athlete development: A practitioner approach. *Journal of Sports Sciences*, *31*(12), 1319–1331. https://doi.org/10.1080/02640414.2013.781661

Güllich, A. (2018). 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), 1–9. https://doi.org/10.1080/02640414.2018.1449089

Halberg, G. V. (2001). *Relationship among power, acceleration, maximum speed, programmed agility, and reactive agility: The neural fundamentals of agility*. (Masters dissertation). Central Michigan University, Mount Pleasant, MI.

Hamill, J., Palmer, C., & Van Emmerik, R. E. A. (2012). Coordinative variability and overuse injury. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology*, *4*(1), 45. https://doi.org/10.1186/1758-2555-4-45

Hammami, M., Negra, Y., Shephard, R. J., & Chelly, M. S. (2017). The effect of standard strength vs. contrast strength training on the development of sprint, agility, repeated change of direction, and jump in junior male soccer players. *Journal of Strength and Conditioning Research*, *31*(4), 901–912. https://doi.org/10.1519/JSC.0000000000001815

Hands, B., McIntyre, F., & Parker, H. (2018). The general motor ability hypothesis: An old idea revisited. *Perceptual and Motor Skills*, *125*(2), 213–233. https://doi.org/10.1177/0031512517751750

Harper, D. J., Jordan, A. R., & Kiely, J. (2018). Relationships between eccentric and concentric knee strength capacities and maximal linear deceleration ability in male academy soccer players. *Journal of Strength and Conditioning Research*, (July), 1. https://doi.org/10.1519/JSC.0000000000002739

Harper, D. J., & Kiely, J. (2018). Damaging nature of decelerations: Do we adequately prepare players? BMJ Open Sport & Exercise Medicine 4(1): e000379. https://doi.org/10.1136/bmjsem-2018-000379

Harre, D. (1982). *Principles of sports training: Introduction to the theory and methods of training* (1st Ed.). Berlin: Sportverlag.

Haugen, T. A., Tønnessen, E., Hisdal, J., & Seiler, S. (2014). The Role and Development of Sprinting Speed in Soccer. *International Journal of Sports Physiology and Performance*, *9*(3), 432–441. https://doi.org/10.1123/ijspp.2013-0121

Havens, K. L., & Sigward, S. M. (2015). Cutting mechanics: Relation to performance and anterior cruciate ligament injury risk. *Medicine and Science in Sports and Exercise*, *47*(4), 818–824. https://doi.org/10.1249/MSS.0000000000000470

Heang, L. J., Hœ, W. E., Quin, C. K., Yin, L. H., Joe Heang, L., Eng Hoe, W., … Yin, L. H. (2012). Effect of plyomteric training on the agility of students enrolled in required college badminton programme. *International Journal of Applied Sports Sciences*, *24*(1), 18–24. Retrieved from http://www.sports.re.kr/eng/05publication/CaUforpaper.jsp

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 Sport Sciences, 18*(9): 727-737.

Hendricks, S., Lambert, M., Masimla, H., & Durandt, J. (2015). Measuring skill in rugby union and rugby league as part of the standard team testing battery. *International Journal of Sports Science & Coaching*, *10*(5), 949–965. https://doi.org/10.1260/1747-9541.10.5.949

Henry, F. M. (1968). Specificity vs. generality in learning motor skill. In: Brown, R. C. and Kenyon, G. S. (eds) *Classical studies on physical activity* (pp. 328–331). Englewood Cliffs, NJ: Prentice-Hall Inc.

Henry, G., Dawson, B., Lay, B., & Young, W. (2011). Validity of a reactive agility test for Australian football. *International Journal of Sports Physiology and Performance*, *6*(4), 534–545. https://doi.org/10.1519/jsc.0b013e318215fa1c

Henry, G. J., Dawson, B., Lay, B. S., & Young, W. B. (2016). Relationships between reactive agility movement time and unilateral vertical, horizontal, and lateral jumps. *Journal of Strength and Conditioning Research*, *30*(9), 2514–2521. https://doi.org/10.1519/JSC.0b013e3182a20ebc

Hewit, J., Cronin, J., Button, C., & Hume, P. (2011). Understanding deceleration in sport. *Strength and Conditioning Journal*, *33*(1), 47–52. https://doi.org/10.1519/SSC.0b013e3181fbd62c

Hiley, M. J., Zuevsky, V. V., & Yeadon, M. R. (2013). Is skilled technique characterized by high or low variability? An analysis of high bar giant circles. *Human Movement Science*, *32*(1), 171–180. https://doi.org/10.1016/j.humov.2012.11.007

Hirano, M., & Funase, K. (2017). Relationship between Motor Module and Motor Skill Learning. *Advances in Exercise and Sports Physiology*, *23*(3), 41–45.

Hollings, S. C., Hopkins, W. G., & Hume, P. A. (2014). Age at peak performance of successful track & field athletes. *International Journal of Sports Science & Coaching*, *9*(4), 651–661. https://doi.org/10.1260/1747-9541.9.4.651

Holloway, K. M., Meir, R. A., Brooks, L. O., & Phillips, C. J. (2008). The Triple-120 Meter Shuttle Test: A sport-specific test for assessing anaerobic endurance fitness in rugby league players. *Journal of Strength and Conditioning Research*, *22*(2), 633–639. https://doi.org/10.1519/JSC.0b013e31816600e9

Hopper, A., Haff, E. E., Barley, O. R., Joyce, C., Lloyd, R. S., & Haff, G. G. (2017). Neuromuscular training improves movement competency and physical performance measures in 11–13-year-old female netball athletes. *Journal of*

Strength and Conditioning Research, *31*(5), 1165–1176. https://doi.org/10.1519/JSC.0000000000001794

Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., McGuigan, M. R., & Nosaka, K. (2008). Does pperformance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? *Journal of Strength and Conditioning Research*, *22*(2), 412–418. https://doi.org/10.1519/JSC.0b013e318166052b

Hulteen, R. M., Morgan, P. J., Barnett, L. M., Stodden, D. F., & Lubans, D. R. (2018). Development of foundational movement skills: A conceptual model for physical activity across the lifespan. *Sports Medicine*, *48*(7), 1533–1540. https://doi.org/10.1007/s40279-018-0892-6

Ibrahim, H. (2009). *Assessing general motor ability and tests for talent identification of malaysian adolescents*. (Doctoral dissertation). Retrieved from http://research-repository.uwa.edu.au/files/3244297/Ibrahim_Halijah_2009.pdf

Ibrahim, H., Hear, N. P., & Blanksby, B. (2011). Exploring the general motor ability construct. *Perceptual and Motor Skills*, *113*(2), 491–508. https://doi.org/10.2466/03.06.19.25.PMS.113.5.491-508

Inaba, Y., Yoshioka, S., Iida, Y., Hay, D. C., & Fukashiro, S. (2013). A biomechanical study of side steps at different distances. *Journal of Applied Biomechanics*, *29*(3), 336–345. https://doi.org/10.1123/jab.29.3.336

Inglis, P., Hons, B., & Bird, S. P. (2016). Reactive agility tests - review and practical applications. *Journal of Australian Strength and Conditioning*, *24*(5), 62–69.

Issurin, V. B. (2013). Training transfer: Scientific background and insights for practical application. *Sports Medicine*, *43*(8), 675–694. https://doi.org/10.1007/s40279-013-0049-6

Issurin, H. (2017). *Athletic talent. Identification and its development*. Muskegon Heights, MI: Ultimate Athletes Concepts

Jaakkola, T., & Washington, T. (2013). The relationship between fundamental movement skills and self-reported physical activity during Finnish junior high school. *Physical Education and Sport Pedagogy*, *18*(5), 492–505. https://doi.org/10.1080/17408989.2012.690386

Jackson, R. C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta Psychologica*, *123*(3), 355–371. https://doi.org/10.1016/j.actpsy.2006.02.002

Jantzen, K. (2007). Neural coordination dynamics of human sensorimotor behavior: A Review. *Handbook of Brain Connectivity*, 2004.

Jayanthi, N. A., LaBella, C. R., Fischer, D., Pasulka, J., & Dugas, L. R. (2015). Sports-Specialized Intensive Training and the Risk of Injury in Young Athletes. *The American Journal of Sports Medicine*, *43*(4), 794–801. https://doi.org/10.1177/0363546514567298

Jayanthi, N., Pinkham, C., Dugas, L., Patrick, B., & LaBella, C. (2013). Sports specialization in young athletes. *Sports Health: A Multidisciplinary Approach*, *5*(3), 251–257. https://doi.org/10.1177/1941738112464626

Jeffreys, I. (2006). Motor Learning-Applications for agility, part 1. *Strength and Conditioning Journal*, *28*(5), 72–76. https://doi.org/10.1519/00126548-200610000-00012

Jeffreys, I. (2011). A task-based approach to developing context-specific agility. *Strength and Conditioning Journal*, *33*(4), 52–59. https://doi.org/10.1519/SSC.0b013e318222932a

Jenkins, W. M., & Merzenich, M. M. (1987). Reorganization of neocortical representations after brain injury: A neurophysiological model of the bases of recovery from stroke. *Progress in Brain Research, 71,* 249–266.

Jess, M., & Collins, D. (2003). Primary physical education in Scotland, *European Journal of Physical Education*, 8, 103-118.

Jess, M., Collins, D., & Burwitz, L. (1998). Children and physical activity: The Centrality of basic movement skill development. Presentation at ICHPER.

Jirsa, V. K., & Kelso, J. A.S. (eds.) (2004). *Coordination dynamics: Issues and trend*s. Berlin: Springer-Verlag.

Jones, P., Bampouras, T. M., & Marrin, K. (2009). An investigation into the physical determinants of change of direction speed. *Journal of Sports Medicine and Physical Fitness*.

Jones, P., Thomas, C., Dos'Santos, T., McMahon, J., & Graham-Smith, P. (2017). The Role of Eccentric Strength in 180° Turns in Female Soccer Players. *Sports*, *5*(2), 42. https://doi.org/10.3390/sports5020042

Jones, B., Weaving, D., Tee, J., Darrall-Jones, J., Weakley, J., Phibbs, P., … Till, K. (2018). Bigger, stronger, faster, fitter: the differences in physical qualities of school and academy rugby union players. *Journal of Sports Sciences*, *00*(00), 1–6. https://doi.org/10.1080/02640414.2018.1458589

Jullien, H., Bisch, C., Largouët, N., Manouvrier, C., Carling, C. J., & Amiard, V. (2008). Does a short period of lower limb strength training improve performance in field-based tests of running and agility in young professional soccer players? *Journal of Strength and Conditioning Research*, *22*(2), 404–411. https://doi.org/10.1519/JSC.0b013e31816601e5

Kiefer, A. W., & Myer, G. D. (2015). Training the Antifragile Athlete: A Preliminary Analysis of Neuromuscular Training Effects on Muscle Activation Dynamics. *Nonlinear Dynamics, Psychology, and Life Sciences*, *19*(4), 489–510.

Kiely, J. (2017). The robust running ape: Unraveling the deep underpinnings of coordinated human running proficiency. *Frontiers in Psychology*, *8*(JUN), 1–10. https://doi.org/10.3389/fpsyg.2017.00892

Kim, T., Chen, J., Verwey, W. B., & Wright, D. L. (2018). Improving novel motor learning through prior high contextual interference training. *Acta Psychologica*, *182*(November 2017), 55–64. https://doi.org/10.1016/j.actpsy.2017.11.005

Kirk, M. A., & Rhodes, R. E. (2011). Motor skill interventions to improve fundamental movement skills of preschoolers with developmental delay. *Adapted Physical Activity Quarterly*, *28*(3), 210–32. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/21725115

Kirkpatrick, J., & Comfort, P. (2013). Strength, power, and speed qualities in english junior elite rugby league players. *Journal of Strength and Conditioning Research*, *27*(9), 2414–2419. https://doi.org/10.1519/JSC.0b013e3182804a6d

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. *Journal of Speech Language and Hearing Research*, *51*(1), S225. https://doi.org/10.1044/1092-4388(2008/018)

Kluwe, M., Miyahara, M., & Heveldt, K. (2012). A case study to evaluate balance training with movement test items and through teaching observation: Beyond specificity and transfer of learning. *Physical Education & Sport Pedagogy*, *17*(5), 463–475. https://doi.org/10.1080/17408989.2011.594428

Kollias, I., Hatzitaki, V., Papaiakovou, G., & Giatsis, G. (2001). Using principal components analysis to identify individual differences in vertical jump performance. *Research Quarterly for Exercise and Sport*, *72*(1), 63–67. https://doi.org/10.1080/02701367.2001.10608933

Kovacs, M. S., Roetert, E. P., & Ellenbecker, T. S. (2008). Efficient deceleration: the forgotten factor in tennis-specific training. *Strength and Conditioning Journal*, *30*(6), 58–69. https://doi.org/10.1519/SSC.0b013e31818e5fbc

Kraemer, W. J., & Looney, D. P. (2012). Underlying Mechanisms and Physiology of Muscular Power. *Strength and Conditioning Journal*, *34*(6), 13–19. https://doi.org/10.1519/SSC.0b013e318270616d

Kushner, A. M., Kiefer, A. W., Lesnick, S., Faigenbaum, A. D., Kashikar-Zuck, S., & Myer, G. D. (2015). Training the developing brain part II. *Current Sports Medicine Reports*, *14*(3), 235–243. https://doi.org/10.1249/JSR.0000000000000150

Kutlu, M., Yapıcı, H., Yoncalık, O., & Çelik, S. (2012). Comparison of a new test for agility and skill in soccer with other agility tests. *Journal of Human Kinetics*, *33*(1), 143–150. https://doi.org/10.2478/v10078-012-0053-1

Landow, L. (2018). Multidirectional training: Teaching the language of movement. *Professional Strength & Conditioning*, (49), 31–38

Larkin, D., Hands, B., Parker, H., Kendall, G., & Sloan, N. (2007). Are we measuring motor ability? In *Progress in Motor Control VI*. Santos, Brazil.

Liefeith, A., Kiely, J., Collins, D., & Richards, J. (2018). Back to the future – in support of a renewed emphasis on generic agility training within sports-specific developmental pathways. *Journal of Sports Sciences*, *36*(19), 2250–2255. https://doi.org/10.1080/02640414.2018.1449088

Little, T., & Williams, A. G. (2005). Specificity of acceleration, maximum speed, and agility in professional soccer players. *The Journal of Strength and Conditioning Research*, *19*(1), 76. https://doi.org/10.1519/14253.1

Lloyd, R. S., Cronin, J. B., Faigenbaum, A. D., Haff, G. G., Howard, R., Kraemer, W. J., … Oliver, J. L. (2016). National Strength and Conditioning Association position statement on long-term athletic development. *Journal of Strength and Conditioning Research*, *30*(6), 1491–1509. https://doi.org/10.1519/JSC.0000000000001387

Lloyd, R. S., Faigenbaum, A. D., Stone, M. H., Oliver, J. L., Jeffreys, I., Moody, J. A., … Myer, G. D. (2014). Position statement on youth resistance training: the 2014 International Consensus. *British Journal of Sports Medicine*, *48*(7), 498–505. https://doi.org/10.1136/bjsports-2013-092952

Lloyd, R. S., & Oliver, J. L. (2012). The Youth Physical Development Model: A new approach to long-term athletic development. *Strength and Conditioning Journal*, *34*(3), 61–72. https://doi.org/10.1519/SSC.0b013e31825760ea

Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Howard, R., De Ste Croix, M. B. A., Williams, C. A., … Myer, G. D. (2015). Long-term athletic development- part 1: a pathway for all youth. *Journal of Strength and Conditioning Research*, *29*(5), 1439–50. https://doi.org/10.1519/JSC.0000000000000756

Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Myer, G. D., & De Ste Croix, M. B. A. (2014). Chronological age vs. biological maturation. *Journal of Strength and Conditioning Research*, *28*(5), 1454–1464. https://doi.org/10.1519/JSC.0000000000000391

Lloyd, R. S., Oliver, J. L., Hughes, M. G., & Williams, C. A. (2012). The effects of 4-weeks of plyometric training on reactive strength index and leg stiffness in male youths. *Journal of Strength and Conditioning Research*, *26*(10), 2812–2819. https://doi.org/10.1519/JSC.0b013e318242d2ec

Lockie, R., Dawes, J., & Jones, M. (2018). Relationships between linear speed and lower-body power with change-of-direction speed in national collegiate athletic association divisions i and ii women soccer athletes. *Sports*, *6*(2), 30. https://doi.org/10.3390/sports6020030

Lockie, R. G., Schultz, A. B., Callaghan, S. J., Jeffriess, M. D., & Berry, S. P. (2013). Reliability and validity of a new test of change-of-direction speed for field-based sports: the change-of-direction and acceleration test (CODAT). *Journal of Sports Science & Medicine*, *12*(1), 88–96. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/24149730

Loockerman, W. D., & Berger, R. A. (1972). Specificity and generality between various directions for reaction and movement times under choice stimulus conditions. *Journal of Motor Behavior*, *4*(1), 31–35. https://doi.org/10.1080/00222895.1972.10734917

Loturco, I., Nimphius, S., Kobal, R., Bottino, A., Zanetti, V., Pereira, L. A., & Jeffreys, I. (2018). Change-of direction deficit in elite young soccer players. *German Journal of Exercise and Sport Research*, *48*(2), 228–234. https://doi.org/10.1007/s12662-018-0502-7

Lubans, D. R., Morgan, P. J., Cliff, D. P., Barnett, L. M., & Okely, A. D. (2010). Fundamental movement skills in children and adolescents. *Sports Medicine*, *40*(12), 1019–1035. https://doi.org/10.2165/11536850-000000000-00000

Lundvall, S. (2015). Physical literacy in the field of physical education – A challenge and a possibility. *Journal of Sport and Health Science*, *4*(2), 113–118. https://doi.org/10.1016/j.jshs.2015.02.001

McCarron, L. T. (1982). *McCarron Assessment of Neuromuscular Development*. (Rev. Ed.) Dallas, TX: Common Market.

McCloy, C. H. (1932). Recent studies in the Sargent jump. *Research Quarterly of the American Physical Education Association*, *3*(2), 235–242. https://doi.org/10.1080/23267402.1932.10622573

McCloy, C. H. (1934). The measurement of general motor capacity and general motor ability. *Research Quarterly. American Physical Education Association*, *5*(sup1), 46–61. https://doi.org/10.1080/23267402.1934.10761657

McGill University. (2018, July 11). 15-minutes of exercise creates optimal brain state for mastering new motor skills: Exercise increases brain connectivity and efficiency. *ScienceDaily*. Retrieved July 27, 2018 from www.sciencedaily.com/releases/2018/07/180711153607.htm

McLean, S. G., Walker, K. B., & van den Bogert, A. J. (2005). Effect of gender on lower extremity kinematics during rapid direction changes: An integrated analysis of three sports movements. *Journal of Science and Medicine in Sport*, *8*(4), 411–422. https://doi.org/10.1016/S1440-2440(05)80056-8

McLean, S. G., Lipfert, S. W., & Van Den Bogert, A. J. (2004). Effect of gender and defensive opponent on the biomechanics of sidestep cutting. *Medicine and Science in Sports and Exercise*, *36*(6), 1008–1016. https://doi.org/10.1249/01.MSS.0000128180.51443.83

McLennan, N., & Thompson, J. (2015). *Quality physical education: guidelines for policy-makers*. Paris: UNESCO Publishing. Retrieved from http://unesdoc.unesco.org/images/0023/002311/231101e.pdf

MacCobb, S., Greene, S., Nugent, J. K., & O'Mahony, P. (2005). Measurement and prediction of motor proficiency in children using the Bayley Infant Scales and the Bruininks-Oseretsky Test. *Physical & Occupational Therapy In Pediatrics*, *25*(1), 59–79. https://doi.org/10.1300/J006v25n01_05

MacMahon, C., Helsen, W. F., Starkes, J. L., & Weston, M. (2007). Decision-making skills and deliberate practice in elite association football referees. *Journal of Sports Sciences*, *25*(1), 65–78. https://doi.org/10.1080/02640410600718640

MacNamara, Á., & Collins, D. (2011). Development and initial validation of the psychological characteristics of developing excellence questionnaire. *Journal of Sports Sciences*, *29*(12), 1273–1286. https://doi.org/10.1080/02640414.2011.589468

MacNamara, Á., Collins, D., Bailey, R., Toms, M., Ford, P., & Pearce, G. (2011). Promoting lifelong physical activity and high level performance: realising an achievable aim for physical education. *Physical Education & Sport Pedagogy*, *16*(3), 265–278. https://doi.org/10.1080/17408989.2010.535200

MacNamara, Á., Collins, D., & Giblin, S. (2015). Just let them play? Deliberate preparation as the most appropriate foundation for lifelong physical activity. *Frontiers in Psychology*, *6*(OCT). https://doi.org/10.3389/fpsyg.2015.01548

Magill, R. A. (1993). *Motor learning: concepts and applications*. Dubuque, IA: Brown & Benchmark.

Magill, R. A. (2001). *Motor learning: concepts and applications* (6th Ed.). Boston, MA: McGraw Hill.

Malina, R. M. (2009). Children and adolescents in the sport culture: The overwhelming majority to the select few. *Journal of Exercise Science & Fitness*, *7*(2), S1–S10. https://doi.org/10.1016/S1728-869X(09)60017-4

Malina, R. M. (2014). Top 10 research questions related to growth and maturation of relevance to physical activity, performance, and fitness. *Research Quarterly for Exercise and Sport*, *85*(2), 157–173. https://doi.org/10.1080/02701367.2014.897592

Marshall, B. M., Franklyn-Miller, A. D., King, E. A., Moran, K. A., Strike, S. C., & Falvey, É. C. (2014). Biomechanical factors associated with time to complete a change of direction cutting maneuver. *Journal of Strength and Conditioning Research*, *28*(10), 2845–2851. https://doi.org/10.1519/JSC.0000000000000463

Marteniuk, R. G. (1974). Individual differences in motor performance and learning. *Exercise and Sport Sciences Reviews*, *2*(1), 103–130.

Matlák, J., Tihanyi, J., & Rácz, L. (2016). Relationship between reactive agility and change of direction speed in amateur soccer players. *Journal of Strength and Conditioning Research*, *30*(6), 1547–1552. https://doi.org/10.1519/JSC.0000000000001262

Meir, R., Holding, R., & Hetherington, J. (2014). Impact of the two-handed rugby ball carry on change of direction speed and reactive agility: Implications for sport specific testing. *International Journal of Sports Science & Coaching*, *9*(5), 1181–1190. https://doi.org/10.1260/1747-9541.9.5.1181

Merzenich, M. M., Van Vleet, T. M., & Nahum, M. (2014). Brain plasticity-based therapeutics. *Frontiers in Human Neuroscience*, *8*(June), 1–16. https://doi.org/10.3389/fnhum.2014.00385

Milanović, Z., Sporiš, G., Trajković, N., James, N., & Samija, K. (2013). Effects of a 12 week SAQ training programme on agility with and without the ball among young soccer players. *Journal of Sports Science & Medicine*, *12*(1), 97–103. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/24149731

Moesch, K., Elbe, A.-M., Hauge, M.-L. 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. https://doi.org/10.1111/j.1600-0838.2010.01280.x

Moradi, J., Movahedi, A., & Salehi, H. (2014). Specificity of learning a sport skill to the visual condition of acquisition. *Journal of Motor Behavior*, *46*(1), 17–23. https://doi.org/10.1080/00222895.2013.838935

Morland, B., Bottoms, L., Sinclair, J., & Bourne, N. (2013). Can change of direction speed and reactive agility differentiate female hockey players? *International*

Journal of Performance Analysis in Sport, *13*(2), 510–521. https://doi.org/10.1080/24748668.2013.11868666

Mostafavifar, A. M., Best, T. M., & Myer, G. D. (2013). Early sport specialisation, does it lead to long-term problems? *British Journal of Sports Medicine*, *47*(17), 1060–1061. https://doi.org/10.1136/bjsports-2012-092005

Myer, G. D., Ford, K. R., Palumbo, J. P., & Hewett, T. E. (2005). Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *Journal of Strength and Conditioning Research*, *19*(1), 51–60. https://doi.org/10.1519/13643.1

Myer, G. D., Jayanthi, N., Difiori, J. P., Faigenbaum, A. D., Kiefer, A. W., Logerstedt, D., & Micheli, L. J. (2015). Sport specialization, part I: Does early sports specialization increase negative outcomes and reduce the opportunity for success in young athletes? *Sports Health: A Multidisciplinary Approach*, *7*(5), 437–442. https://doi.org/10.1177/1941738115598747

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: A Multidisciplinary Approach*, *8*(1), 65–73. https://doi.org/10.1177/1941738115614811

Naclerio, F., & Faigenbaum, A. (2011). Integrative neuromuscular training for youth. *Kronos*, *10*(I), 49–56.

Nedergaard, N. J., Kersting, U., & Lake, M. (2014). Using accelerometry to quantify deceleration during a high-intensity soccer turning manoeuvre. *Journal of Sports Sciences*, *32*(20), 1897–1905. https://doi.org/10.1080/02640414.2014.965190

Neilson, P. D., & Neilson, M. D. (2005). Motor maps and synergies. *Human Movement Science*, *24*(5–6), 774–97. https://doi.org/10.1016/j.humov.2005.09.008

Newell, K. M., Broderick, M. P., Deutsch, K. M., & Slifkin, A. B. (2003). Task goals and change in dynamical degrees of freedom with motor learning. *Journal of Experimental Psychology: Human Perception and Performance, 29*(2), 379–387.

Nimphius, S. (2014). Increasing agility. In D. Joyce & D. Lewindon (Eds.), *High-Performance Training for Sports* (pp. 185–198). Champaign, IL: Human Kinetics.

Nimphius, S., Callaghan, S. J., Bezodis, N. E., & Lockie, R. G. (2018). Change of direction and agility tests. *Strength and Conditioning Journal*, *40*(1), 26–38. https://doi.org/10.1519/SSC.0000000000000309

Nimphius S, Callaghan SJ, & Hawser A. (2016, July). *Comparison of Simplified Change of Direction Tests*. Paper session presented at National Strength and Conditioning Association Conference: New Orleans, LA

Nimphius, S., Callaghan, S. J., Spiteri, T., & Lockie, R. G. (2016). Change of direction deficit. *Journal of Strength and Conditioning Research*, *30*(11), 3024–3032. https://doi.org/10.1519/JSC.0000000000001421

Nimphius, S., Mcguigan, M. R., & Newton, R. U. (2010). Relationship between strength, power, speed, and change of direction performance of female softball players. *Journal of Strength and Conditioning Research*, *24*(4), 885–895. https://doi.org/10.1519/JSC.0b013e3181d4d41d

O' Brien, W., Belton, S., & Issartel, J. (2016). Fundamental movement skill proficiency amongst adolescent youth. *Physical Education and Sport Pedagogy*, *21*(6), 557–571. https://doi.org/10.1080/17408989.2015.1017451

O'keeffe, S. L., Harrison, A. J., & Smyth, P. J. (2007). Transfer or specificity? An applied investigation into the relationship between fundamental overarm throwing and related sport skills. *Physical Education & Sport Pedagogy*, *12*(2), 89–102. https://doi.org/10.1080/17408980701281995

Okely, A. D., Booth, M. L., & Chey, T. (2004). Relationships between body composition and fundamental movement skills among children and adolescents. *Research Quarterly for Exercise and Sport, 75*(3), 238–247. https://doi.org/10.1080/02701367.2004.10609157

Oliver, J. L., & Meyers, R. W. (2009). Reliability and generality of measures of acceleration, planned agility, and reactive agility. *International Journal of Sports Physiology and Performance, 4*(3), 345–54. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19953822

Page, M. J. (2017) *Multidimensional perfectionism and the cortisol awakening response in athletes* (unpublished Masters dissertation). York St John University, York, UK.

Page, P., & Ellenbecker, T. S. (Eds.). (2003). *The scientific and clinical application of elastic resistance*. Champaign, IL: Human Kinetics.

Pallant, J., (2010). *SPSS survival manual: A step by step guide to data analysis using the SPSS program* (4th Ed.). New York: McGraw Hill.

Paszkewicz, J., Webb, T., Waters, B., Welch McCarty, C., & Van Lunen, B. (2012). The effectiveness of injury-prevention programs in reducing the incidence of anterior cruciate ligament sprains in adolescent athletes. *Journal of Sport Rehabilitation, 21*(4), 371–7. https://doi.org/10.1123/jsr.21.4.371

Paul, D. J., Gabbett, T. J., & Nassis, G. P. (2016). Agility in team sports: Testing, training and factors affecting performance. *Sports Medicine, 46*(3), 421–442. https://doi.org/10.1007/s40279-015-0428-2

Pearson, A., & International, S. A. Q. (2001). *Speed, agility and quickness for soccer : SAQ soccer*. London: A. & C. Black.

Pelletier, R., Higgins, J., & Bourbonnais, D. (2015). Is neuroplasticity in the central nervous system the missing link to our understanding of chronic musculoskeletal disorders? *BMC Musculoskeletal Disorders*, *16*(1), 25. https://doi.org/10.1186/s12891-015-0480-y

Peugh, J. L., & Enders, C. K. (2005). Using the SPSS mixed procedure to fit cross-sectional and longitudinal multilevel models. *Educational and Psychological Measurement, 65*(5), 717-741

Phillips, E., Davids, K., Renshaw, I., & Portus, M. (2010). Expert Performance in Sport and the Dynamics of Talent Development. *Sports Medicine*, *40*(4), 271–283. https://doi.org/10.2165/11319430-000000000-00000

Pichardo, A. W., Oliver, J. L., Harrison, C. B., Maulder, P. S., & Lloyd, R. S. (2018). Integrating models of long-term athletic development to maximize the physical development of youth. *International Journal of Sports Science & Coaching*, *0*(0), 174795411878550. https://doi.org/10.1177/1747954118785503

Planinsec, J., & Pisot, R. (2006). Motor coordination and intelligence level in adolescents. *Adolescence*, *41*(164), 667–76.

Plisk, S. S. (2000). Speed, agility, and speed-endurance development. In: *Essentials of strength training and conditioning* (pp. 471–491). Champaign, IL: Human Kinetics

Polman, R., Walsh, D., Bloomfield, J., & Nesti, M. (2004). Effective conditioning of female soccer players. *Journal of Sports Sciences*, *22*(2), 191–203. https://doi.org/10.1080/02640410310001641458

Preatoni, E., Hamill, J., Harrison, A. J., Hayes, K., Van Emmerik, R. E. A., Wilson, C., & Rodano, R. (2013). Movement variability and skills monitoring in sports. *Sports Biomechanics*, *12*(2), 69–92. https://doi.org/10.1080/14763141.2012.738700

Proteau, L., Marteniuk, R. G., & Lévesque, L. (1992). A sensorimotor basis for motor learning: evidence indicating specificity of practice. *The Quarterly Journal of Experimental Psychology Section A*, *44*(3), 557–575. https://doi.org/10.1080/14640749208401298

Raczek, J., Juras, G., & Waśkiewicz, Z. (2001). The diagnosis of motor coordination. *Journal of Human Kinetics*, *6*(April), 113–125.

Read, P. J., Oliver, J. L., Myer, G. D., De Ste Croix, M. B. A., & Lloyd, R. S. (2018). The effects of maturation on measures of asymmetry during neuromuscular control tests in elite male youth soccer players. *Pediatric Exercise Science*, *30*(1), 168–175. https://doi.org/10.1123/pes.2017-0081

Robinson, L. E., Stodden, D. F., Barnett, L. M., Lopes, V. P., Logan, S. W., Rodrigues, L. P., & D'Hondt, E. (2015). Motor competence and its effect on positive developmental trajectories of health. *Sports Medicine*, *45*(9), 1273–1284. https://doi.org/10.1007/s40279-015-0351-6

Ross, A., Leveritt, M., & Riek, S. (2001). Neural influences on sprint running. *Sports Medicine*, *31*(6), 409–425. https://doi.org/10.2165/00007256-200131060-00002

Sanctuary, C. E., Meir, R., & Sadler, I. (2012). The seven step approach to the application of sports science in english professional rugby league: Practical considerations in strength and conditioning. *International Journal of Sports Science & Coaching*, *7*(1), 33–45. https://doi.org/10.1260/1747-9541.7.1.33

Sands, W. A., McNeal, J. R., Jemni, M., & Delong, T. H. (2000). Should female gymnasts lift weights. *Sportscience*, *4*(3), 1–6.

Sanna, G., & O'Connor, K. M. (2008). Fatigue-related changes in stance leg mechanics during sidestep cutting maneuvers. *Clinical Biomechanics*, *23*(7), 946–954. https://doi.org/10.1016/j.clinbiomech.2008.03.065

Santos, S., Mateus, N., Sampaio, J., & Leite, N. (2017). Do previous sports experiences influence the effect of an enrichment programme in basketball skills? *Journal of Sports Sciences*, *35*(17), 1759–1767. https://doi.org/10.1080/02640414.2016.1236206

Sargent, D. A. (1921). The physical test of a man. *American Physical Education Review*, 26, 188-194.

Sasaki, S., Nagano, Y., Kaneko, S., Sakurai, T., & Fukubayashi, T. (2011). The relationship between performance and trunk movement during change of direction. *Journal of Sports Science & Medicine*, *10*(1), 112–118. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/24149303

Sassi, R. H., Dardouri, W., Yahmed, M. H., Gmada, N., Mahfoudhi, M. E., & Gharbi, Z. (2009). Relative and absolute reliability of a modified agility t-test and its relationship with vertical jump and straight sprint. *Journal of Strength and Conditioning Research*, *23*(6), 1644–1651. https://doi.org/10.1519/JSC.0b013e3181b425d2

Sayers, M. G. L. (2015). Influence of test distance on change of direction speed test results. *Journal of Strength and Conditioning Research*, *29*(9), 2412–2416. https://doi.org/10.1519/JSC.0000000000001045

Scanlan, A., Humphries, B., Tucker, P. S., & Dalbo, V. (2014). The influence of physical and cognitive factors on reactive agility performance in men basketball players. *Journal of Sports Sciences*, *32*(4), 367–374. https://doi.org/10.1080/02640414.2013.825730

Scanlan, A. T., Wen, N., Kidcaff, A. P., Berkelmans, D. M., Tucker, P. S., & Dalbo, V. J. (2016). Generic and sport-specific reactive agility tests assess different qualities in court-based team sport athletes. *The Journal of Sports Medicine and Physical Fitness*, *56*(3), 206–13. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/25389640

Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review*, *82*(4), 225-260

Schmidt, R.A., & Lee, T.D. (1999). *Motor control and learning: A behavioral emphasis* (3rd Ed.). Champaign, IL: Human Kinetics.

Schmidt, R. A., & Lee, T. D. (2014). *Motor learning and performance from principles to application*. Champaign: Human Kinetics.

Schot, P., Dart, J., & Schuh, M. (1995). Biomechanical analysis of two change-of-direction maneuvers while running. *Journal of Orthopaedic & Sports Physical Therapy*, *22*(6), 254–258. https://doi.org/10.2519/jospt.1995.22.6.254

Seifert, L., Button, C., & Davids, K. (2013). Key properties of expert movement systems in sport: An ecological dynamics perspective. *Sports Medicine*, *43*(3), 167–178. https://doi.org/10.1007/s40279-012-0011-z

Sekulic, D., Krolo, A., Spasic, M., Uljevic, O., & Peric, M. (2014). The development of a new stop'n'go reactive-agility test. *Journal of Strength and Conditioning Research*, *28*(11), 3306–3312. https://doi.org/10.1519/JSC.0000000000000515

Serpell, B. G., Ford, M., & Young, W. B. (2010). The development of a new test of agility for rugby league. *Journal of Strength & Conditioning Research*, *24*(12), 3270–3277. https://doi.org/10.1519/JSC.0b013e3181b60430

Sever, O., Arslanoğlu, E., & Arslanoğlu, E. (2016). Agility, acceleration, speed and maximum speed relationship with age factor in soccer players. *Journal of Human Sciences*, *13*(3), 5660–5667. https://doi.org/10.14687/jhs.v13i3.4152

Shea, C. H., & Kohl, R. M. (1990). Specificity and variability of practice. *Research Quarterly for Exercise and Sport*, *61*(2), 169–177. https://doi.org/10.1080/02701367.1990.10608671

Sheppard, J. M., & Young, W. B. (2006). Agility literature review: classifications, training and testing. *Journal of Sports Sciences*. https://doi.org/10.1080/02640410500457109

Sheppard, J. M., Young, W. B., Doyle, T. L. A., Sheppard, T. A., & Newton, R. U. (2006). An evaluation of a new test of reactive agility and its relationship to sprint speed and change of direction speed. *Journal of Science and Medicine in Sport, 9*(4), 342–349. https://doi.org/10.1016/j.jsams.2006.05.019

Sherar, L. B., Baxter-Jones, A. D. G., Faulkner, R. A., & Russell, K. W. (2007). Do physical maturity and birth date predict talent in male youth ice hockey players? *Journal of Sports Sciences, 25*(8), 879–886. https://doi.org/10.1080/02640410600908001

Silverman, S., & Mercier, K. (2015). Teaching for physical literacy: Implications to instructional design and PETE. *Journal of Sport and Health Science, 4*(2), 150–155. https://doi.org/10.1016/j.jshs.2015.03.003

Simonek, J., Horicka, P., & Hianik, J. (2016). Differences in pre-planned agility and reactive agility performance in sport games. *Acta Gymnica*, *46*(2), 68–73. https://doi.org/10.5507/ag.2016.006

Smart, D., Hopkins, W. G., Quarrie, K. L., & Gill, N. (2014). The relationship between physical fitness and game behaviours in rugby union players. *European Journal of Sport Science, 14*(sup1), S8–S17. https://doi.org/10.1080/17461391.2011.635812

Smith, M. M. (2015). Early sport specialization: A Historical Perspective. *Kinesiology Review*, *4*(3), 220–229. https://doi.org/10.1123/kr.2015-0024

Spasic, M., Krolo, A., Zenic, N., Delextrat, A., & Sekulic, D. (2015). Reactive agility performance in handball; development and evaluation of a sport-specific measurement protocol. *Journal of Sports Science & Medicine*, *14*(3), 501–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/26336335

Spiteri, T., Cochrane, J. L., Hart, N. H., Haff, G. G., & Nimphius, S. (2013). Effect of strength on plant foot kinetics and kinematics during a change of direction task.

European Journal of Sport Science, *13*(6), 646–652. https://doi.org/10.1080/17461391.2013.774053

Spiteri, T., Hart, N. H., & Nimphius, S. (2014). Offensive and defensive agility: A sex comparison of lower body kinematics and ground reaction forces. *Journal of Applied Biomechanics*, *30*(4), 514–520. https://doi.org/10.1123/jab.2013-0259

Spiteri, T., Newton, R. U., Binetti, M., Hart, N. H., Sheppard, J. M., & Nimphius, S. (2015). Mechanical Determinants of Faster Change of Direction and Agility Performance in Female Basketball Athletes. Journal of Strength and Conditioning Research, 29(8), 2205–2214. https://doi.org/10.1519/JSC.0000000000000876

Starkes, J. L., Cullen, J D., & MacMahon, C. (2004). A life-span model of the acquisition and retention of expert perceptual-motor performance. In A. M. Williams & N. J. Hodges (Eds.), *Skill Acquisition in Sport: Research, theory and practice* (pp. 259-281). London: Routledge.

Stodden, D. F., Goodway, J. D., Langendorfer, S. J., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A developmental perspective on the role of motor skill competence in physical activity: An Emergent Relationship. *Quest*, *60*(2), 290–306. https://doi.org/10.1080/00336297.2008.10483582

Stodden, D., Langendorfer, S., & Roberton, M. A. (2009). The association between motor skill competence and physical fitness in young adults. *Research Quarterly for Exercise and Sport*, *80*(2), 223–229. https://doi.org/10.1080/02701367.2009.10599556

Suchomel, T. J., Comfort, P., & Lake, J. P. (2017). Enhancing the force-velocity profile of athletes using weightlifting derivatives. *Strength and Conditioning Journal*, *39*(1), 10–20. https://doi.org/10.1519/SSC.0000000000000275

Sugimoto, D., Stracciolini, A., Dawkins, C. I., Meehan, W. P., & Micheli, L. J. (2017). Implications for Training in Youth. *Strength and Conditioning Journal*, *39*(2), 77–81. https://doi.org/10.1519/SSC.0000000000000289

Thomas, J. R., & French, K. E. (1985). Gender differences across age in motor performance. A Meta-Analysis. *Psychological Bulletin*, *98*(2), 260–282. https://doi.org/10.1037/0033-2909.98.2.260

Thompson, A. K., & Wolpaw, J. R. (2014). The Simplest Motor Skill. *Exercise and Sport Sciences Reviews*, *42*(2), 82–90. https://doi.org/10.1249/JES.0000000000000010

Thorndike, E.L. (1914). *Educational psychology: Briefer course*. NY, Columbia: University Press.

Threlkeld, A. J., Horn, Terry, S., Wojtowicz, Geralyn, M., Rooney, James, G., & Shapiro, R. (1989). Kinematics, ground reaction force, and muscle balance produced by backward running. *The Journal of Orthopaedic and Sports Physical Therapy*, *11*(2), 56–63.

Till, K., Tester, E., Jones, B., Emmonds, S., Fahey, J., & Cooke, C. (2014). Anthropometric and physical characteristics of english academy rugby league players. *Journal of Strength and Conditioning Research*, *28*(2), 319–327. https://doi.org/10.1519/JSC.0b013e3182a73c0e

Torres, C. R. (2015). Better Early Than Late? A philosophical exploration of early sport specialization. *Kinesiology Review*, *4*(3), 304–316. https://doi.org/10.1123/kr.2015-0020

Tribolet, R., Bennett, K. J. M., Watsford, M. L., & Fransen, J. (2018). A multidimensional approach to talent identification and selection in high-level youth Australian Football players. *Journal of Sports Sciences*, *00*(00), 1–7. https://doi.org/10.1080/02640414.2018.1468301

Tschacher, W. & Dauwalder, J-P. (Eds.) (1999). *Dynamics, synergetics, autonomous agents—nonlinear systems approaches to cognitive psychology and cognitive science*. Singapore: World Scientific.

Turner, A. (2011). The science and practice of periodization: A brief review. *Strength and Conditioning Journal*, *33*(1), 34–46. https://doi.org/10.1519/SSC.0b013e3182079cdf

Turner, A. N., & Stewart, P. F. (2013). Repeat sprint ability. *Strength and Conditioning Journal*, *35*(1), 37–41. https://doi.org/10.1519/SSC.0b013e3182824ea4

Ulrich D. (2000). *Test of Gross Motor Development (2nd Ed.) Examiner's Manual*. Austin, Texas: PRO-ED.

Valovich McLeod, T. C., Decoster, L. C., Loud, K. J., Micheli, L. J., Parker, J. T., Sandrey, M. A., & White, C. (2011). National Athletic Trainers' Association Position Statement: Prevention of Pediatric Overuse Injuries. *Journal of Athletic Training*, *46*(2), 206–220. https://doi.org/10.4085/1062-6050-46.2.206

Vandendriessche, J. B., Vaeyens, R., Vandorpe, B., Lenoir, M., Lefevre, J., & Philippaerts, R. M. (2012). Biological maturation, morphology, fitness, and motor coordination as part of a selection strategy in the search for international youth soccer players (age 15–16 years). *Journal of Sports Sciences*, *30*(15), 1695–1703. https://doi.org/10.1080/02640414.2011.652654

Vandorpe, B., Vandendriessche, J., Vaeyens, R., Pion, J., Matthys, S., Lefevre, J., … Lenoir, M. (2012). Relationship between sports participation and the level of motor coordination in childhood: A longitudinal approach. *Journal of Science and Medicine in Sport*, *15*(3), 220–225. https://doi.org/10.1016/j.jsams.2011.09.006

Van Hooren, B., & Bosch, F. (2016). Influence of muscle slack on high-intensity sport performance. *Strength and Conditioning Journal*, *38*(5), 75–87. https://doi.org/10.1519/SSC.0000000000000251

Vanrenterghem, J., Venables, E., Pataky, T., & Robinson, M. A. (2012). The effect of running speed on knee mechanical loading in females during side cutting. *Journal of Biomechanics*, *45*(14), 2444–2449. https://doi.org/10.1016/j.jbiomech.2012.06.029

Van Waelvelde, H., Peersman, W., Lenoir, M., & Smits Engelsman, B. C. (2007). The reliability of the Movement Assessment Battery for Children for preschool children with mild to moderate motor impairment. *Clinical Rehabilitation*, *21*(5), 465–470. https://doi.org/10.1177/0269215507074052

Vescovi, J. D., & Mcguigan, M. R. (2008). Relationships between sprinting, agility, and jump ability in female athletes. *Journal of Sports Sciences*, *26*(1), 97–107. https://doi.org/10.1080/02640410701348644

Waldén, M., Hägglund, M., & Ekstrand, J. (2007). Football injuries during European Championships 2004–2005. *Knee Surgery, Sports Traumatology, Arthroscopy*, *15*(9), 1155–1162. https://doi.org/10.1007/s00167-007-0290-3

Waldron, M., Worsfold, P. R., Twist, C., & Lamb, K. (2014). The relationship between physical abilities, ball-carrying and tackling among elite youth rugby league players. *Journal of Sports Sciences*, *32*(6), 542–549. https://doi.org/10.1080/02640414.2013.841975

Wheeler, K. W., & Sayers, M. G. L. (2010). Modification of agility running technique in reaction to a defender in rugby union. *Journal of Sports Science & Medicine*, *9*(3), 445–451.

Wheeler, K. W., & Sayers, M. G. L. (2011). Rugby Union contact skills alter evasive agility performance during attacking ball carries. *International Journal of Sports Science & Coaching*, *6*(3), 419–432. https://doi.org/10.1260/1747-9541.6.3.419

Wheeler, K. W., Wiseman, R., & Lyons, K. (2011). Tactical and technical factors associated with effective ball offloading strategies during the tackle in rugby league. *International Journal of Performance Analysis in Sport*, *11*(2), 392–409. https://doi.org/10.1080/24748668.2011.11868558

Whitehead, M. (2001). The concept of physical literacy. *European Journal of Physical Education, 6*(2), 127–138. https://doi.org/10.1080/1740898010060205

Whitehead, M. (2013). The history and development of physical literacy. *International Council of Sport Science and Physical Education Bulletin*, *65*, 22–28. Retrieved from https://www.icsspe.org/sites/default/files/bulletin65_0.pdf#page=98

Whitely, S. E. (1983). Construct validity: Construct representation versus nomothetic span. *Psychological Bulletin, 93*(1), 179–197.

Wiersma, L. D. (2000). Risks and benefits of youth sport specialization: Perspectives and recommendations. *Pediatric Exercise Science*, *12*(1), 13–22. https://doi.org/10.1123/pes.12.1.13

Willis, G. (2005). *Cognitive Interviewing*. Thousand Oaks, CA. SAGE Publications Inc. https://doi.org/10.4135/9781412983655

Wilson, C., Simpson, S., Van Emmerik, R., & Hamill, J. (2008). Coordination variability and skill development in expert triple jumpers. *Sports Biomechanics*, *7*(1), 2–9. https://doi.org/10.1080/14763140701682983

Wolpaw, J. R., & Tennissen, A. M. (2001). Activity-dependent spinal cord plasticity in health and disease. *Annual Review of Neuroscience*, *24*(1), 807–843. https://doi.org/10.1146/annurev.neuro.24.1.807

Wulf, G., & Shea, C. H. (2002). Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychonomic Bulletin & Review*, *9*(2), 185–211. https://doi.org/10.3758/BF03196276

Young, W. B. (2006). Transfer of strength and power training to sports performance. *International Journal of Sports Physiology and Performance, 1*(2), 74–83. https://doi.org/10.1123/ijspp.1.2.74

Young, W., & Farrow, D. (2006). A review of agility: Practical applications for strength and conditioning. *Strength and Conditioning Journal*, *28*(5), 24. https://doi.org/10.1519/1533-4295(2006)28[24:AROAPA]2.0.CO;2

Young, W., & Farrow, D. (2013). The importance of a sport-specific stimulus for training agility. *Strength and Conditioning Journal*, *35*(2), 39–43. https://doi.org/10.1519/SSC.0b013e31828b6654

Young, W. B., James, R., & Montgomery, I. (2002). Is muscle power related to running speed with changes of direction? *The Journal of Sports Medicine and Physical Fitness*, *42*(3), 282–8.

Young, W. B., McDowell, M. H., & Scarlett, B. J. (2001). Specificity of sprint and agility training methods. *The Journal of Strength and Conditioning Research*, *15*(3), 315–319. https://doi.org/10.1519/1533-4287(2001)015<0315:SOSAAT>2.0.CO;2

Young, W. B., Miller, I. R., & Talpey, S. W. (2015). Physical qualities predict change-of-direction speed but not defensive agility in Australian rules football. *Journal of Strength and Conditioning Research*, *29*(1), 206–212. https://doi.org/10.1519/JSC.0000000000000614

Young, W. B., & Willey, B. (2010). Analysis of a reactive agility field test. *Journal of Science and Medicine in Sport*, *13*(3), 376–378. https://doi.org/10.1016/j.jsams.2009.05.006

Zatsiorsky, V. M. (2002). Biomechanics of strength and strength training. In: Komi P.V. (Ed.) *Strength and power in sport* (2nd ed, pp. 439–487). London: Blackwell.

Zemková, E. (2017). Agility index as a measurement tool based on stimuli number and traveling distances. *Journal of Strength and Conditioning Research*, *31*(8), 2141–2146. https://doi.org/10.1519/JSC.0000000000001647

Zemková, E., & Hamar, D. (2018). Association of speed of decision making and change of direction speed with the agility performance. *Journal of Functional Neurology Rehabilitation and Ergonomics*, *7*(4) 10-15.

Appendix A

Coaches' rating of performance questionnaire (U15s & U16s academy players - technical and skill review) **Coach Name:**

To support the reviewing process of the current under 15sand 16s academy players we would like to collect some information, could we therefore ask you to complete the table below. Please rate the players from your perspective on a number of technical, skill, and playing orientated traits. Using a scale of 1-10, 1 being a score of the least competency/performance and 10 being the best competency/performance score, could you rate each individual player on all items.

Name		Technical competence 1 (handling, kicking)	Technical competence 2 (tackling)	Playing ability (tactical awareness, support play, reading the game environment)	Mental toughness, ("spirit" , mental robustness)	Practical awareness (alertness, focus)	Physical competence 1 (physical robustness, protection from injury)	Physical competence 2 (General co-ordination, natural ability, athletic prowess)	Teamwork (social ability, communication, interactivity)	Intellect (ability to learn new skills, cognitive skills, decision making)	Courage (heart of a lion, commitment to task)

Definitions and guidance:

1. Technical competence 1 – handling – kicking

    - Rate the player's technical ability in those sophisticated skills that are the basis of rugby league

2. Technical competence 2 – tackling skills that require

    - Rate the player's technical ability is those skills which requires physical presence

3. Playing ability - tactical awareness – support play – reading the game environment

    - Rate tactical awareness, the player's understanding games play

4. Mental toughness – "spirit" – mental robustness

    - How the player copes, their attitude

5. Practical awareness – alertness – focus

    - The player's ability to pay attention and show awareness of their surroundings

6. Physical competence 1 - physical robustness – protection from injury

    - The survival rating for a player

7. Physical competence 2 General co-ordination - natural ability – athletic prowess

    - Rate the player's athleticism

8. Teamwork – social ability – communication – interactivity

    - How a player can integrate and communicate

9. Intellect - ability to learn new skills – cognitive skills – decision making

    - Rate the player's psychological abilities related to games play

10. Courage – "heart of a lion" – commitment to task

    - How the player approaches adversity and challenges

Appendix B

WMAT Protocol

The WMAT (adapted from Yuhasz in Campbell & Tucker, 1967) consists of four test components. At least 30 min recovery was allowed between each test. A standardised familiarisation and practice period of five min on each test component was allowed before commencing the WMAT.

Agility run.

Four obstacles are positioned 3.05 m apart (the original dimensions used in WMAT were in imperial units, conversion to SI units created unique metric dimensions), and a start and finish line were marked. A further two obstacles were placed in line with the last obstacle at a distance of 1.83 m away from it. Participants positioned with the chest on the floor began the test under their own volition from behind the start line. Participants negotiated the course as shown in Figure 1. Each participant was timed using an electronic timing system (Smartspeed, Brisbane, Australia). The fastest of two attempts was used for analysis.

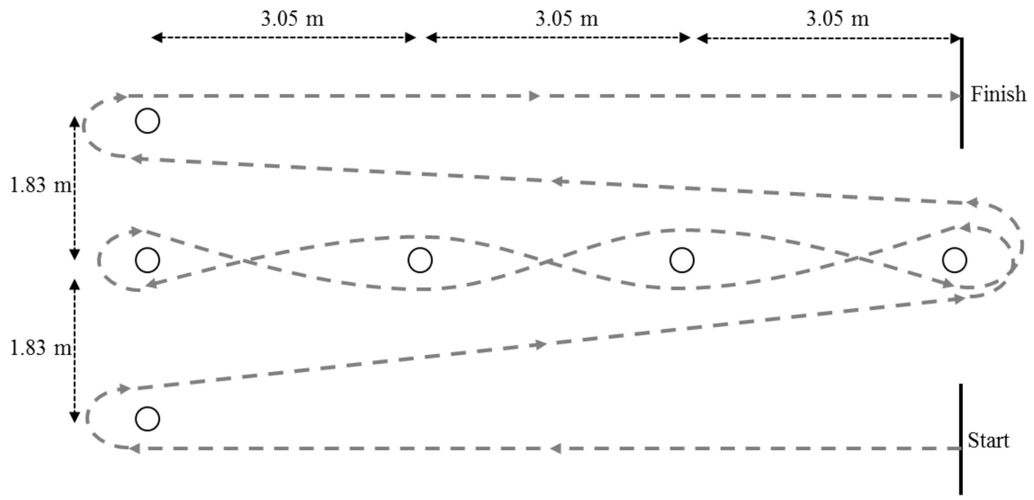

Figure 1. Agility run course

Standing broad jump.

A restraining line was marked on the floor. Participants stood with feet behind the line and slightly apart. From the standing position, they jumped as far forward as possible. A whole body countermovement including the use of the arms was allowed before take-off. The distance was measured from the start line to the body part which was closest to it on landing and was measured using a tape measure affixed to the floor by a trained researcher. The further of two attempts was used for analysis.

Alternate hand wall toss.

A restraining line was marked on the floor 1.89 m from a flat surfaced wall; which the participant stood behind. The participant started with one ball in their dominant hand, and extra balls were made available in a container by their side. Using an underhand technique, each participant threw the ball against the wall and caught it in the opposite hand. With this hand the participant then threw it against the wall and caught it with the starting hand. This throwing action was repeated as many times as possible for a 30 s period. The ball could be caught in an overhand position; however, it had to be thrown underhand. The catch had to be *clean*, and the ball could not be trapped between a hand and another body part. A score was generated by counting the number of valid catches in each hand within the period verified by a trained researcher. Each participant was allowed a single attempt at the test.

Sitting basketball throw

A restraining line was marked on the floor. Participants sat with their legs straight and apart with heels behind the line. The participant balanced a regulation size basketball (size seven) in their dominant open hand, palm side up. Each participant threw the basketball as far as they could using an over-hand bent-arm technique while remaining in a seated position and legs extended, the heels must remain on the floor at all times. Bowling or pushing actions were not permitted. The flexion and extension of the torso was permitted to assist the throw, providing all other criteria was met. The distance of two throws was measured using a tape measure affixed to the floor, verified by a trained researcher. The farthest of two throws was used for analysis.

Appendix C

Scholarship Conditioning Schedule - Mesocycle 3-4

Mesocycle 3 & 4 (12 weeks) incorporating: generic agility development (including CoD mechanics [pre-planned & reactive]), anaerobic capacity, muscular strength

<table>
<tr><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th><th>Saturday</th><th>Sunday</th></tr>
<tr><td colspan="7">Weeks 13-18 (8rd January – 16th February)</td></tr>
<tr><td>Under 15's
GBC @ WC
17.45-19.00
GMA (Technical, FMS)/Muscular endurance (ME) Strength</td><td rowspan="2">Rest</td><td rowspan="2">Under 15/16's
FBC @ Dewsbury
Evening 17.45-20.00
Anaerobic intervals (volume/increasing intensity) & GMA (Technical, FMS), CoD (Pre-planned and reactive), problem based movements</td><td rowspan="2">Rest</td><td rowspan="2">Unsupervised work
Anaerobic intervals (volume/increasing intensity) & technical/Muscular endurance (ME)</td><td rowspan="2">Under 15/16's
FBC @ Dewsbury
Morning 09.00-11.00
CoD (Mechanics, problem based movements), Field based strength & Anaerobic Conditioning</td><td rowspan="2">Own Club games</td></tr>
<tr><td>Under 16's
GBC @ WC
19.00-20.00
GMA (Technical, FMS)/Muscular endurance (ME) Strength & Plyometrics (low intensity)</td></tr>
<tr><td colspan="7">Stretching every day (develop range of movement (ROM) at major joints, hold each stretch for a minimum of 30 secs)
Supplementary Training (appropriate supplementary training on other identified days)</td></tr>
<tr><td colspan="7">Weeks 19-24 (19th February – 30th March)</td></tr>
<tr><td>Under 15's
GBC @ WC
17.45-19.00
GMA (Technical, FMS) /Muscular endurance (ME) Strength</td><td rowspan="2">Rest</td><td rowspan="2">Under 15/16's
FBC @ Dewsbury
Evening 17.45-20.00
Anaerobic intervals (volume/increasing intensity) & GMA (Technical, FMS), CoD (Pre-planned and reactive), problem based movements</td><td rowspan="2">Rest</td><td rowspan="2">Unsupervised work
Anaerobic intervals (volume/increasing intensity) & technical/Muscular endurance (ME)</td><td rowspan="2">Under 15/16's
FBC @ Dewsbury
Morning 09.00-11.00
CoD (Mechanics, problem-based movements), Field based strength & Anaerobic Conditioning</td><td rowspan="2">Own Club games</td></tr>
<tr><td>Under 16's
FBC @ WC
19.00-20.00
GMA (Technical, FMS) /Muscular endurance (ME) Strength & Plyometrics (low intensity)</td></tr>
<tr><td colspan="7">Stretching every day (develop range of movement (ROM) at major joints, hold each stretch for a minimum of 30 secs)
Supplementary Training (appropriate supplementary training on other identified days)</td></tr>
</table>

Key	**Field Based Conditioning (FBC)**		**Gym Based Conditioning (GBC)**
1	Medium intensity/medium-high volume	1	Low intensity
2	Medium intensity/medium volume	2	Medium intensity
3	High intensity/lower volume	3	High intensity

Monday Gym Based Programme

Exercise	Reps	Sets	Weight Lifted Record Week 1	Week 2	Week 3	Week 4
B drill (20 m)	2	X2				
SVJ (controlled, big & fast)	10					
Barbell rollout	10					
DB Shoulder Press	8					
			H	**M**	**H**	**M**
Wide chins	5	X3				
Back squat	6					
Bilateral and unilateral hurdle hopping (variation)	4					
Movement challenge (1)	6					
Dumbbell jerk	6ES	X3				
Single leg squat (25-30 kg) 10 ES	6					
Dumbbell walking lunge (20 m)	2					
Leg lifts + twist	10					
			M	**H**	**M**	**H**
Hang clean	6	X3				
A drill (15 m) & standing triple jump ES	4 (2 each)					
Press up (weighted)	10					
Walkers raise	8	X2				
RDL walk (20 m)	4 (2 each)					
Movement challenge (2)	20					

M –Medium weight for 3 sets, H - Heavy weight for 2 of 3 sets with a build-up set, VH – set a new RM.

Wednesday Field Based Programme

Exercise	Reps	Sets	
Session 1 (Running around field)			
Hotspot 1: Mini Carnegie	X3	X2	Up and down
Hotspot 2: Commandos and seals (10 m) etc.	X2		Groundwork, strength & ME
Hotspot 3: Slalom & sprint	X6		Cone slalom with 45^0 CoD sprints
Hotspot 4: Movement challenge	X6		Generic agility
Hotspot 5: Group challenge	X4		Group communication, decision making
Hotspot 6: Acceleration sprints	X6		10 m acceleration zone → 20 m sprint
Session 2			
Running around the pitch	X2	X2/3	2 laps, sprinting widths (8 s) jogging lengths
Contact Carnegie's with wrestle (5-10-5 m)	X4		2 each. Working in pairs, Each run into contact, and wrestle (5 s)
Movement challenge	X6		Generic agility variation
Sprints (10 m)	X?		Chest to the ground (variation)
Session 3			
Hill intervals	X1	X1	10-20-30-40-30-20-10 m, jog recovery
Triangles (reactionary)	X12		3 coloured triangles (3 m – blue, red, yellow), player reacts to colour call.
Hill intervals	X1		10-20-30-40-30-20-10 m, jog recovery
Mini-Carnegie (1.5-3-1.5 m)			Up and down!
Hill intervals	X1		10-20-30-40-30-20-10 m, jog recovery
Movement challenge	X3		Generic agility variation
Sprints (10 m)	X?		Chest to the ground

Static Stretch (stretch everyday)

A range of stretches for whole body muscle groups, hold each stretch for 30-60 seconds.

Appendix D

Boys KS4: Teaching Groups

Yr9 Options / Exam Subjects

Option 1	L	R	Option 2	L	R	Option 3	L	R	Option 4	L	R	Option 5	L	R
Football (3G)	GME	DTL	Basketball (SH)	GME	DTL	Table Tennis (G)	GME	DTL	Badminton (SH)	DTL	TRO	Cricket (F)	GME	DTL
Table Tennis (G)	LSH	TRO	Football (3G)	LSH	INE	Football (3G)	DTL	INE	Hockey (C)	LSH	DTL	Handball (3G)	DTL	TRO
Circuit Training (*)	DTL	INE	Rugby (F)	DTL	TRO	Am. Football (3G)	LSH	TRO	Weight Training (FS)	GME	INE	Tennis (C)	LSH	INE
Sep 4th -Nov 3rd	8 wk		Nov 6th - Jan 12th	8 wk		Jan 15th - Mar 16th	8 wk		Mar 19th - May 25th	8 wk		June 4th - July 20th	7wk	

Yr 10 Options / Exam Subjects

Option 1	L	R	Option 2	L	R	Option 3	L	R	Option 4	L	R	Option 5	L	R
Football (3G)	**GME**	**GME**	**Basketball (SH)**	**RLE**	**DTL**	**BTEC Practical (G)**	**RLE**	**LSH**	**Rugby (F)**	**DTL**	**DTL**	**Table Tennis (G)**	**GME**	**GME**
Table Tennis (G)	**RLE**	**DTL**	**Football (3G)**	**JTR**	**GME**	**Football (3G)**	**GME**	**DTL**	**Badminton (SH)**	**RLE**	**GME**	**Handball (3G)**	**JTR**	**DTL**
Circuit Training (*)	**DTL**	**LSH**	**Am. Football (3G)**	**GME**	**LSH**	**Hockey (C)**	**DTL**	**GME**	**Weight Training (FS)**	**JTR**	**LSH**	**Tennis (C)**	**DTL**	**LSH**
Sep 4th - Nov 3rd	8 wk		Nov 6th - Dec 22nd	7 wk		Jan 8th - Mar 2nd	7 wk		Mar 5th - May 4th	7 wk		May 7th - July 20th	10 wk	

Yr 11 Options / Exam Subjects

Option 1	L	R	Option 2	L	R	Option 3	L	R	Option 4	L	R
Basketball (G)	DTL	DTL	Badminton (SH)	LSH	RLE	GCSE Practical	DTL	DTL	Handball (3G)	DTL	LSH
Football (3G)	LSH	RLE	Football (3G)	DTL	DTL	Hockey (C)	RLE	LSH	Tennis (C)	LSH	RLE
Circuit Training (FS)	RLE	LSH	Football (3G)	RLE	LSH	Football (3G)	LSH	RLE	Cricket (F)	RLE	DTL
Sep 5th - Nov 4th	8 wk		Nov 7th - Jan 13th	8 wk		Jan 16th - Mar 17th	8 wk		Mar 20th - May 26th	8 wk	

Appendix E

Multilevel Modelling Syntax for SPSS

Assessing the relationship between PT, $Decel_{1,}$ $Decel_2$, $PVel_1$, $PVel_2$ and GMA.

Level 1 unconditional linear growth models.

Model below is for PT

MIXED PT WITH Wave

/PRINT = SOLUTION TESTCOV

/METHOD =ML

/FIXED = INTERCEPT Wave

/RANDOM INTERCEPT Wave | SUBJECT(Participant) COVTYPE(UN).

Model below is for Decel_1

MIXED Decel_1 WITH Wave

/PRINT = SOLUTION TESTCOV

/METHOD =ML

/FIXED = INTERCEPT Wave

/RANDOM INTERCEPT Wave | SUBJECT(Participant) COVTYPE(UN).

Model below is for Decel_2

MIXED Decel_2 WITH Wave

/PRINT = SOLUTION TESTCOV

/METHOD =ML

/FIXED = INTERCEPT Wave

/RANDOM INTERCEPT Wave | SUBJECT(Participant) COVTYPE(UN).

Model below is for Peak_Velocity_1

MIXED Peak_Velocity_1 WITH Wave

/PRINT = SOLUTION TESTCOV

/METHOD =ML

/FIXED = INTERCEPT Wave

/RANDOM INTERCEPT Wave | SUBJECT(Participant) COVTYPE(UN).

Model below is for Peak_Velocity_2

MIXED Peak_Velocity_2 WITH Wave

/PRINT = SOLUTION TESTCOV

/METHOD =ML

/FIXED = INTERCEPT Wave

/RANDOM INTERCEPT Wave | SUBJECT(Participant) COVTYPE(UN).

Level 2 conditional linear growth models.

Model below is for PT with the GMA groups

MIXED PT WITH Wave GMA_MS_Sigma

/PRINT = SOLUTION TESTCOV

/METHOD = ML

/FIXED = INTERCEPT Wave GMA_MS_Sigma Wave*GMA_MS_Sigma

/RANDOM INTERCEPT Wave | SUBJECT(Participant) COVTYPE(UN).

Model below is for Decel_1 with the GMA groups

MIXED Decel_1 WITH Wave GMA_MS_Sigma

/PRINT = SOLUTION TESTCOV

/METHOD = ML

/FIXED = INTERCEPT Wave GMA_MS_Sigma Wave*GMA_MS_Sigma

/RANDOM INTERCEPT Wave | SUBJECT(Participant) COVTYPE(UN).

Model below is for Decel_2 with the GMA groups

MIXED Decel_2 WITH Wave GMA_MS_Sigma

/PRINT = SOLUTION TESTCOV

/METHOD = ML

/FIXED = INTERCEPT Wave GMA_MS_Sigma Wave*GMA_MS_Sigma

/RANDOM INTERCEPT Wave | SUBJECT(Participant) COVTYPE(UN).

Multilevel Modelling Syntax for SPSS

MIXED Peak_Velocity_1 WITH Wave GMA_MS_Sigma

/PRINT = SOLUTION TESTCOV

/METHOD = ML

/FIXED = INTERCEPT Wave GMA_MS_Sigma Wave*GMA_MS_Sigma

/RANDOM INTERCEPT Wave | SUBJECT(Participant) COVTYPE(UN).

Model below is for Peak_Velocity_2 with the GMA groups

MIXED Peak_Velocity_2 WITH Wave GMA_MS_Sigma

/PRINT = SOLUTION TESTCOV

/METHOD = ML

/FIXED = INTERCEPT Wave GMA_MS_Sigma Wave*GMA_MS_Sigma

/RANDOM INTERCEPT Wave | SUBJECT(Participant) COVTYPE(UN).

Appendix F

List of published material from this thesis:

Liefeith, A., Kiely, J., Collins, D., & Richards, J. (2018). Back to the Future – in support of a renewed emphasis on generic agility training within sports-specific developmental pathways. *Journal of Sports Sciences*, *36*(19), 2250–2255. https://doi.org/10.1080/02640414.2018.1449088