Executive Function in Children With and Without Developmental Coordination Disorder

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Context of the research

This PhD studentship was funded by the publisher Hogrefe Ltd. and the research was undertaken as part of the UK standardisation project for the Intelligence and Development Scales for Children and Adolescents – 2nd Edition (IDS-2). The IDS-2 is a broad assessment battery designed to measure Intelligence, Executive Function, Psychomotor skills, Social-emotional skills, Scholastic skills and Motivation and Attitude in participants aged 5 to 20 years. The participants described in this thesis completed the full IDS-2 and the data contributed to the UK norms. However, only data from the IDS-2 Executive Function and Psychomotor components are reported in this thesis. At the time of writing this thesis the IDS-2 norms and standard scores were not yet published so only raw scores from the Executive Function and Psychomotor components are reported.

Abstract

Background**:** Children with Developmental Coordination Disorder (DCD) have motor difficulties which impact their everyday activities. Difficulties with Executive Function (EF) are commonly reported with relationships between EF and motor skills poorly understood. A key component of EF is Inhibition, important for classroom learning and less explored in children with DCD. Study One aimed to investigate the EF skills of children with and without DCD focusing on Inhibition, and Study Two aimed to examine relationships between Inhibition and motor skills.

Method: Participants were 25 children with DCD aged six-ten years, and 25 age and gender matched typically developing (TD) children. They completed experimental measures of Inhibition, standardised tests of motor and EF skills, and parents and teachers completed standardised EF questionnaires.

Results:

Study One. Children with DCD had significantly poorer performance on some experimental and standardised measures of Inhibition and on parent and teacher reports of overall EF skills. Inhibition difficulties were reported by parents but not teachers. Results emphasize the potential for task and environmental demands to influence EF and Inhibition performance.

Study Two. Significant relationships between at least one Inhibition measure and all areas of motor skills were found across groups. However, relationships differed across motor domains and Inhibition measures. Many within group correlations were also significant, although there was variation across the DCD and TD groups. This suggests that relationships between EF and motor skills are different for those with and without DCD.

Conclusion: Children with DCD have difficulties with Inhibition across a range of measures and some aspects of performance are associated with their level of motor skills. The motor and Inhibition difficulties observed in children with DCD appear to be interdependent. Assessment of children with DCD should include an examination of Inhibition skills. Interventions should consider development of Inhibition as well as motor skills.

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1. General Introduction

Movement is essential for participation in everyday life. Motor skills enable interaction with the environment and are necessary for participation in most activities of daily life such as self-care (e.g. grooming, eating), leisure (e.g. playing sports, walking in the park) and productivity (e.g. navigating the school or work environment, handwriting, typing) (Townsend & Polatajko, 2007). From birth, movement skills influence a person's ability to learn from their environment (Adolph & Hoch, 2019). The ability to manipulate objects and negotiate the physical environment provides opportunities for goal directed behaviour and early problem solving. Therefore, motor skills and higher order cognitive skills are closely associated (von Hofsten, 2009). However, these two systems have been mostly studied in isolation.

Chapter two starts by outlining Developmental Coordination Disorder (DCD), a condition which is characterised by the atypical development of motor skills. The Canadian Model of Occupational Performance and Engagement (CMOP-E) (Townsend & Polatajko, 2007) is used to both outline the impact that DCD can have on a child's everyday life and to emphasize the individual impact personal, task, and environmental factors have on performance and participation for children with the condition. DCD is detectable in early childhood and impacts a child's ability to carry out everyday activities such as those listed above. Whilst the diagnostic criteria for DCD focuses on poor motor skills (American Psychiatric Association, 2013), difficulties often extend beyond the motor domain to other areas such as Executive Function skills (Blank et al., 2019).

Executive Function skills are higher order cognitive skills that enable a person to engage in goal directed behaviour. Debate exists regarding the exact nature of Executive Function and this is outlined in chapter three. However, it is generally agreed that Executive Function consists of separate domains which share an underlying commonality. The most frequently cited domains are Working Memory, Mental Flexibility and Inhibition. Whilst children with DCD have been reported to have difficulties with Executive Function, not all domains have been investigated in detail and methodological limitations restrict the confidence with which conclusions can be drawn. This is discussed in more detail in chapter four. Evidence of Executive Function difficulties in children with DCD suggest that there may be a relationship between Executive Function and motor skills in children. Further evidence for a relationship between Executive Function and motor skills comes from their similar developmental trajectories (Diamond, 2000; Piek et al., 2012) and co-activation of neural pathways (Abe & Hanakawa, 2009; Diamond, 2000; Hanakawa, 2011). However, there is limited research which has focused on relationships between individual domains of Executive Function (e.g. Inhibition) and motor skills specifically. This is discussed in chapter five.

It is important to understand the full profile of difficulties experienced by children with DCD. This can further the theoretical understanding of the condition and have practical implications. Having a detailed understanding of the common areas of difficulty and strength for children with DCD can ensure that children receive a comprehensive assessment. This can inform support plans to minimise the impact of their difficulties on everyday life and guide intervention to improve their skills. Executive Function skills are not routinely assessed in a clinical DCD assessment. Therefore, difficulties with activities such as organising belongings for school, staying focused on a task and following class instructions could go unidentified. Consequently, gaining a greater understanding of the Executive Function skills of children with and without DCD can have important practical implications for both assessment and interventions. In addition, having a more in depth understanding of how Executive Function and motor skills relate to each other can also further the theoretical understanding of DCD and could influence directions for intervention research.

The aim of this research was to further the understanding of the Executive Function skills of children with and without DCD. Chapter six outlines the methods used for the two studies completed to meet this aim. Study One (chapter seven) investigates the Executive Function skills of children with and without DCD with a focus on Inhibition and chapter eight discusses these findings in relation to the predictions made in chapter four. Study Two (chapter nine) investigates the relationships between measures of Inhibition and motor skills and chapter ten discusses these findings. Chapter eleven, then provides a general discussion of the collective results, the theoretical and practical implications in relation to children with DCD as well as other developmental disorders and suggests directions for future work.

2. Developmental Coordination Disorder

2.1. Introduction

Developmental Coordination Disorder (DCD) is a condition in which poor motor control and coordination negatively impact on participation in everyday life. These difficulties are evident in the early developmental period and cannot be explained by an intellectual disability, visual impairment or neurological condition (e.g. cerebral palsy) (American Psychiatric Association, 2013). The effects are often present across all areas of life for example, self-care (e.g. dressing, grooming), leisure (e.g. joining in sports, playing with Lego) and productivity (e.g. meeting the handwriting demands of school). Table 2.1. provides a description of the everyday presentation of two children with the condition.

Table 2.1.

Case Descriptions from Study Participants

Pseudonyms	Description
Karl	Aged ten, Karl is in year five at primary school. He appears to be a very bright child and is particularly interested in maths and science. He struggles to meet the handwriting demands at school as his handwriting is difficult to read and effortful for him to produce. Karl also takes much longer to complete his work than his classmates. Whilst he is talented at maths and science, he finds using rulers very challenging which can impede his performance. Karl dislikes Physical Education lessons and finds ball games particularly challenging. At break time he tends to sit alone and read, whilst his classmates play games such as football. At lunchtime, he has a packed lunch as he is unable to use cutlery independently. Karl is generally quiet and well behaved; however, he gets in trouble with his teacher for looking 'scruffy' because his shirt is often untucked, and for frequently misplacing items needed for school such as his pencil case.
Caroline	Aged seven, Caroline is in year three at primary school. She is very energetic and enthusiastic, but she is falling behind her peers at school. She finds reading and spelling particularly challenging but has a very good memory and vocabulary. Caroline has difficulties at school; her handwriting is hard to read and she is often told off for calling out in class or talking at inappropriate times. She also has difficulties focusing her attention and is easily distracted. Caroline finds Physical Education lessons very challenging and experiences greater difficulties than her peers when trying to learn a new motor activity and has recently given up trying to ride her bike. Caroline has a close group of friends with whom she plays role play and barbie doll games. She finds making friendship bracelets difficult and only attempts these when one of her parents is available to help her.

Table 2.1. highlights a range of motor difficulties children with DCD experience. Gross motor skills are the ability to use the larger muscles in the body to complete big movements such as running and jumping. Difficulties with gross motor skills and coordination are evident in Caroline's difficulties learning to ride a bike and Karl's avoidance of football. Karl's case study highlights difficulties with ball skills both in P.E. and at playtime. Both Karl and Caroline also have difficulties with handwriting which is a fine motor and visuomotor activity. These case studies highlight the impact that difficulties with motor skills have on Karl and Caroline's everyday life and the effect that this can have on school performance as well as leisure time. These case studies also highlight that motor difficulties can affect both the quality and speed of performance. Karl's case study emphasises that the motor difficulties he experiences result in him requiring a longer time to complete his work compared to his classmates. It is important to note that whilst both Karl and Caroline have DCD they do not necessarily experience the same pattern of difficulty with motor skills and the impact on everyday life is different for both of them.

Whilst DCD is primarily a motor disorder, the case studies in Table 2.1. also demonstrate that difficulties extend beyond the motor domain. These include difficulties in social skills, emotional regulation (the ability to effectively manage emotional responses), aspects of scholastic achievement (e.g. language and literacy) and Executive Function (Blank et al., 2019). Executive Function is higher level cognition used to achieve goal directed behaviour (Miyake et al., 2000). These skills are required in activities such as packing a bag for school, as well as in aspects of behavioural control such as staying in a seat for the duration of a lesson (Kirby et al., 2011). Whilst there is increasing recognition of difficulties with Executive Function in individuals with DCD (Wilson et al., 2017), there is still a lack of consensus as to what these are and how they are most appropriately measured (Leonard & Hill, 2015). Furthermore, questions remain regarding whether Executive Function difficulties are related to the difficulties that children with DCD experience with motor skills or if they simply co-occur. The overall aim of this research is to further the knowledge of the motor and Executive Function skills in DCD and the relationship between them. This could inform the current understanding of DCD and nature of the individual patterns of difficulties observed in children with DCD in everyday life.

The current chapter provides an outline of DCD, and the contemporary theoretical approaches to the condition. It also considers the diagnostic process and assessment tools used for this, as well as the commonly co-occurring non-motor difficulties. Next, the impact that DCD has on aspects of everyday life is considered, as well as the interventions which are commonly used with this population and the positive effect that these can have on children with DCD.

2.2. Prevalence and Persistence

DCD is a common condition which occurs across different countries, cultures, races and socio-economic conditions (Blank et al., 2019). Prevalence rates vary widely from 0.8%, identified using the full diagnostic criteria with children aged between six to fifteen in Southern India (Girish et al., 2016), to 19% identified using motor performance tasks with children in Greece aged ten to twelve years (Tsiotra et al., 2006). The most commonly cited prevalence rates are between five and six percent (American Psychiatric Association, 2013; Blank et al., 2019; Blank et al., 2012). Whilst there are potentially cultural differences within the epidemiology of DCD, the wide variation appears largely dependent on how stringently the DCD diagnostic criteria are applied (Blank et al., 2019). DCD is generally more commonly identified in males compared to females with male:female ratios ranging from 2:1 in a UK study (Lingam et al., 2009) to 7:1 in a study in Sweden (Kadesjo & Gillberg, 1998). Girish et al. (2016) is the only study to have found a higher occurrence in females compared to males with male:female ratios of 1:2 in Southern India and some studies report similar rates of DCD in males and females (Pearsall-Jones et al., 2009). Some have suggested there are identification biases favouring the identification of males and that girls may be underdiagnosed (Missiuna, Gaines et al., 2006). Sex ratios from a population-based sample of children is unknown (Missiuna, Gaines et al., 2006).

DCD has previously been considered as a disorder of childhood, however, longitudinal studies have shown that the motor difficulties experienced in children with DCD do not disappear naturally over time (Cantell & Kooistra, 2002; Losse et al., 1991). It is now recognised in the International Guidelines for DCD, that DCD persists into adulthood in more than half of children who receive a diagnosis (Blank et al., 2019). Research in motor development over time in DCD has been under-studied in favour of a focus on current snapshots of motor performance

(Barnett et al., 2019). This has resulted in a dearth of knowledge regarding individual trajectories of motor development and a lack of well-controlled longitudinal studies which consider a full account of motor learning opportunities and the extent of engagement in motor activities in individuals with DCD (Blank et al., 2019).

2.3. Terminology

Historically many different terms have been used to describe what is now referred to most frequently in the academic literature as Developmental Coordination Disorder (Chambers et al., 2005). These terms commonly refer to the presentation of the movement difficulties experienced in individuals with the condition, for example, ‘Clumsy Children’ or suggests potential underlying causes for the condition, for example ‘Minimal Brain Dysfunction’ (Clements, 1966). The International Classification of Diseases Version 11 (ICD-11) uses the term ‘Developmental Motor Coordination Disorder’ (World Health Organization, 2018) to refer to the same population. The terms ‘Dyspraxia’ or ‘Developmental Dyspraxia’ have also historically been used to refer to the same group of individuals (Missiuna & Polatajko, 1995). This term continues to remain popular and is used in the title of the UK DCD support group ‘The Dyspraxia Foundation’. There continues to be much debate in the UK regarding the use of different terms and individuals with DCD themselves may have preferences. However, the latest International Guidelines for DCD recommend use of the term DCD for all research purposes.

2.4. Theoretical Frameworks to Understand DCD

DCD is categorised as a Neurodevelopmental Disorder (American Psychiatric Association, 2013). This label reflects the early manifestation of the difficulties and also suggests some form of atypical brain function (Thapar et al., 2017). Despite the label’s focus on neurology, neurodevelopmental disorders typically have multifaceted causal mechanisms rather than a single major cause for the difficulties observed (Thapar et al., 2017). DCD itself is a complex condition which is idiopathic in nature (Blank et al., 2019). However, within the last ten years research has been conducted with greater rigor, enabling results to be synthesised and theories of underlying processes and mechanisms explored (Wilson et al., 2017). Wilson et al. (2017) conducted a large systematic review to examine the existing experimental work across behavioural and neuroimaging studies between

2011 and 2016. This review has led to the proposal of several tentative hypotheses of underlying mechanisms, three of which are outlined in section 2.4.1., having been selected as being most relevant to the research presented in this thesis. Whilst no theory alone has gained universal acceptance, previous research results have been considered alongside the Dynamic Systems Theory (Thelen, 1989, Blank et al., 2019) that recognises development as emerging from a range of bodily systems as well as interactions between the person, the activities they engage in, and the environments in which these occur. There is growing consensus that research evidence should be considered collectively within an integrated framework that accounts for this dynamic interaction (Newell, 1986). Consideration of this dynamic interplay is central to models used by allied health practitioners in Occupational Therapy.

Occupational therapists are interested in understanding how disorders such as DCD impact daily life. In occupational therapy these activities of daily living are called occupations. Occupations are divided into three categories: self-care (e.g. brushing teeth, dressing), productivity (e.g. school, work) and leisure (e.g. football, cinema trips). Occupational therapists use the Canadian Model of Occupational Performance and Engagement (CMOP-E) (Townsend & Polatajko, 2007) to conceptualise how performance of these meaningful occupations can be supported or constrained by the **person**, the **occupation** itself, and the **environment** in which it is performed. The CMOP-E maps directly onto the individual, task and environment model (Newell, 1986) mentioned above. It is the model adopted in this chapter to provide an overview of some of the theoretical approaches taken to understand how and why DCD may impact on the occupational participation of those with the condition. In the following sections factors relating to the ‘person’, ‘occupation’ and ‘environment’ are considered in turn.

2.4.1. Factors Relating to the Person

Research investigating underlying mechanisms of DCD have traditionally focused on individual, or within-person, influences which contribute to the poor motor skills and occupational challenges people experience (Blank et al., 2019). Whilst there are many theories which have been proposed, this section provides an overview of the three which are most relevant to this research. These are, Automatisation

Deficits and Limited Attention Capacity, Executive Function Deficits and Biological Mechanisms. Automatisation Deficits and Limited Attention Capacity has been chosen because Executive Function and Inhibition specifically are often assessed in the context of a motor response. Therefore, difficulties with skill automatisation and limited attentional resources could impact on the ability of children with DCD to successfully Inhibit motor responses. The theory of Executive Function difficulties underlying the motor difficulties in children with DCD is considered because Executive Function and motor skills are the focus of this research. Finally, biological mechanisms for DCD are considered because there is evidence of shared underlying neural networks for both motor and Executive Function skills (Diamond, 2000). Therefore, biological mechanisms could therefore influence both a child's motor and Executive Function skills.

As mentioned previously in 2.4. neurodevelopmental disorders typically have multifaceted causal mechanisms. Therefore, the theories discussed here may not be entirely dissociable and may all have an influence on the performance of children with DCD. For example, difficulties with skill automatisation may be caused by Executive Function difficulties which may in turn be caused by biological mechanisms. Whilst it is important to be mindful of the potential synergies between these theories they can be described separately and are therefore presented individually here.

2.4.1.1. Automatisation Deficit and Limited Attention Capacity. As a motor skill is learnt, elements become automatised (e.g. walking at a steady pace). This enables the task to be completed without attention being paid to the production of the movement (Clark, 2015), enabling attention to be directed elsewhere without effecting the production of that movement (Schott et al., 2016). The Automatisation Deficit Hypothesis (Fawcett & Nicolson, 1992) stems from literature on Dyslexia and evidence has also been found in individuals with DCD (Schott et al., 2016; Tsai, Yu et al., 2009). This impacts occupational performance in activities such as walking (Smits-Engelsman & Wilson, 2013) and the production of handwriting (Chang & Yu, 2010; Jolly & Gentaz, 2014). Prunty et al. (2013) found that children with DCD writing in English are slower at producing handwriting because they spend more time pausing while writing, while the speed of the moving pen is the same as peers with typical development. Chang and Yu (2010) found that the handwriting velocity of children with DCD depended on the complexity of the Chinese characters, with slower velocity associated with more complex characters. Jolly and Gentaz (2010) found that a child with DCD writing in French had an increased number of pen strokes when writing in a cursive style compared to typically developing peers. Jolly and Gentaz (2010) argue that these examples provide evidence of motor skill automatisation difficulties in children with DCD. Difficulties with motor skill automatisation could explain why children with DCD appear to have greater difficulty with tasks that require more complexity (Adams et al., 2016, 2017). When a skill is automatised it requires little attentional-capacity to complete, whereas when a skill has not been automatised, attention demands are much higher (Lang, 2006; Magil & Anderson, 2014).

Theories of limited attention capacity suggest that attentional resources are finite and that a person is only able to meet simultaneous task demands as long as their attention capacity limit has not been exceeded (Kahneman, 1973). Individuals who are yet to automatise a motor skill utilise ‘skill-based attention’ in which they focus on elements associated with task performance. Individuals who have automatised the action are able to have ‘environment focused attention’ and attend to demands beyond the procedural aspects of the task (Beilock et al., 2002; Magil & Anderson, 2014). Similar to the CMOP-E model, Kahneman, (1973) highlights that attention capacity varies depending on individual, task, and environmental factors. It is possible that children with DCD take longer or are unable to automatise basic motor skills compared to their typically developing peers. Therefore, when cognitive demands are added to these tasks, such as the spelling necessary when writing or the planning needed in sports, children with DCD are less able to meet these demands.

2.4.1.2. Executive Function Deficits. The motor difficulties that children with DCD experience have also been explained by difficulties with Executive Function. Executive Function will be described briefly here and in detail in chapter three. Executive Function constitutes higher level thinking skills required to achieve goal directed behaviour and self-regulation (Diamond, 2013). Executive Function consists of individual components which are distinct and also share underlying commonality (Miyake et al., 2000). The most commonly researched components of Executive Function are: Inhibition which is the ability to override automatic but unhelpful responses and ignore distracting information, Working Memory which is the ability to hold information in short term memory for use, and

Mental Flexibility which is the ability to switch flexibly between tasks or mental sets (Diamond, 2013). Children and adults with DCD have been widely reported to experience difficulties with Executive Function (Blank et al., 2019; Wilson et al., 2017). Wilson et al. (2017) has proposed that Executive Function skills are important for motor skill automatisation which, as mentioned previously, evidence suggests could be impaired in children with DCD. In a meta-analysis Wilson et al. (2017) found evidence that the motor difficulties of children with DCD are dependent on the nature of the task and that difficulties are most apparent in tasks with greater complexity, dual tasks and tasks that require complex planning. This suggests that the motor difficulties that children with DCD experience may be directly affected by Executive Function difficulties. Ruddock et al. (2016) provides evidence that the coupling of online control of movement (the ability to update movement plans quickly to respond to a sudden or unexpected demand) and inhibitory control systems follow an atypical pattern in children with DCD compared to those without. In a cross-sectional study including children with and without DCD aged six to twelve years, Ruddock et al. (2016) found that children with DCD had a slower rate of improvement of coupling online motor control and executive control compared to TD peers. Ruddock et al. (2016) argued that Executive Function difficulties in children with DCD could directly influence their motor control ability. However, it is unclear if the Executive Function difficulties reported in children with DCD are a causal mechanism to their motor difficulties of if they are a co-occurring difficulty (Blank et al., 2019). Furthermore, studies of Executive Function in DCD need to be interpreted with caution (Wilson et al., 2017). This is because many have several methodological limitations such as the range and suitability of the tasks used. There is also variation in measurements between studies, and a lack of consistency both in the definition of Executive Function and identification of participants with DCD (Leonard & Hill, 2015). This will be explored in more detail in chapter three.

2.4.1.3. Biological Mechanisms. No single biological origin for DCD has been found. Research on the biological mechanisms of DCD have found a high heritability of up to 70% (Lichtenstein et al., 2010; Martin et al., 2006), however, research investigating DNA and genetics in DCD is rare (Licari et al., 2019). The greatest area of research concerned with the ‘biology’ of the condition comes from brain imaging studies. Differences have been observed within multiple brain regions in individuals with DCD (Wilson et al., 2017). In an activation likelihood estimation meta-analysis, Fuelscher et al. (2018) found that children with DCD had reduced activation in a number of brain regions during a manual dexterity task. These regions included the parietal lobe, parts of the frontal lobe and the cerebellum. Biotteau et al. (2016) in a review of neuroimaging studies in DCD concluded that the cerebellum, parietal lobe and parts of the frontal lobe, including the dorsolateral prefrontal cortex are "unquestionably linked to DCD" (Biotteau et al., 2016, p. 1). All these areas have also been associated with Executive Function performance (Biotteau et al., 2016; Diamond, 2000). As well as motor difficulties, children with DCD have also been found to experience difficulties with Executive Function skills, language and literacy (Blank et al., 2019). It has been suggested that cerebellar dysfunction could account for this range of difficulties (Brookman et al., 2013). The cerebellum had previously been considered to be devoted to motor control however, within the last twenty years evidence has shown the cerebellum to be important for motor, Executive Function, language and learning skills (Brookman et al., 2013; Diamond, 2000; Koziol et al., 2012; Stoodley, 2012). Biotteau et al. (2016) found that children with DCD also had atypical involvement of the basal ganglia. The basal ganglia has been associated with skill automatisation (Biotteau et al., 2016), which, as discussed previously (section 2.4.1.1) is evidenced to be an area of difficulty for children with DCD (Schott et al., 2016). However, results from neuroimaging research have variable findings, likely due to the range of motor tasks and analysis methods used (Licari et al., 2019). Neuroimaging research in DCD has also been hindered by small sample sizes, missing data and a lack of concurrent behavioural measures (Blank et al., 2019). Therefore, caution is needed when interpreting results. Furthermore, it is not yet possible to determine whether any of the brain differences detected in DCD relate to underlying causes or if they are the product of the reduced social and physical participation often reported in DCD (Bishop, 2007; Wilson et al., 2017).

2.4.2. Factors relating to the Occupation

The performance of children with DCD is also influenced by the demands of the occupation of interest. Many experimental tasks have been used to investigate occupation level influences on performance. These tasks vary in terms of their demands (e.g. response modality, temporal and spatial features, single/dual task, number of components) enabling the impact that these demands have on performance to be considered. Motor learning studies in DCD have shown the impact of task features on performance (Wilson et al., 2017). Children with DCD were found to perform worse in procedural learning tasks in which there was a separation of the response device (keyboard) and the stimulus display (screen) (Gheysen et al., 2011; Wilson et al., 2013). However, children with DCD were not found to perform worse in procedural learning tasks when using a touchscreen, which is arguably a more intuitive response (Lejeune et al., 2013) or when completing a sequential finger tapping task (Biotteau et al., 2015). Jarus et al. (2015) also showed deficits in motor learning for individuals with DCD using a complex novel continuous tracking task which required the use of a joystick. The difference in these findings could relate to limited attention capacity discussed in section 2.4.1.1. When response locations are more intuitive (such as using a touch screen), or the response is less complex (e.g. the sequential finger tapping task) less attentional resources are required to respond. This enables children to direct greater attention resources to the other demands of the task which could result in improved performance. This research highlights the need to consider task demands when interpreting research results as well as the important role of task demands when considering theoretical frameworks to understand DCD.

2.4.3. Factors relating to the Environment

Environmental factors also contribute to the engagement and participation in occupations for children with DCD (Blank et al., 2019). Du et al., (2020) investigated environmental risk factors for DCD in a population-based study in China. They found that one child status and higher levels of parental education were a risk factor for DCD. Du et al. (2020) suggest that these results may be because parents of single children may be more protective and therefore expose their child to fewer motor challenges, furthermore a lack of siblings may also limit motor activity. Du et al. (2020) also highlight that parents with higher levels of education are more likely to have a child at a later age. This increases the risk of premature birth which was also found to be a risk factor for DCD (Du et al., 2020).

Using the CMOP-E model the environment is divided into the cultural, physical, social, and institutional environments a person interacts in, and all these environmental contexts can influence the occupational performance of children with DCD. Cultural environments may impact on the types of occupational challenges which are experienced and the impact of a child's motor difficulties on occupational performance. It is possible that the cultural environment may also influence the sex imbalance in the identification of children with DCD which has been highlighted previously (section 2.2.). In many western cultures, for example, it is more common for boys to engage in organised sporting activities compared to girls (Slater & Tiggemann, 2011). From pre-school age girls are reported to engage in less physical activity than boys with this continuing into adulthood (Edwards & Sackett, 2016). Therefore, a boy not wishing to participate in sport may be more noticeable than a girl, which could contribute to a greater identification of DCD in males.

The physical environment can be a barrier or a facilitator to occupational participation and engagement for children with DCD. A child with DCD, for example, may experience difficulties moving around a small and busy classroom, however, they may not experience these difficulties if the classroom was more spacious and had less students. The social environment is composed of family and friends, this environmental factor impacts the occupational choices children with DCD make, as well as how they view themselves. A child with a family willing and able to support their performance challenges may be better able to learn more motor skills and engage in more occupations compared to a child with a family who are less able to focus attention on supporting them. For children with DCD this social environment may also impact the extent to which difficulties are identified and therefore the support that can be provided. A child with DCD, in a family who are keen cyclists may, for example, be identified more easily than a child with a family who have more sedentary hobbies. The institutional environment also impacts on occupational participation and engagement. For children with DCD this includes the school environment as well as the wider political and economic environment. A child with DCD attending a school which allows additional time for practice and differentiated instruction, for example, will have an increased likelihood of enjoying and participating during Physical Education lessons, than a child in a school that does not have these accommodations (Blank et al., 2019).

2.4.4. Summary of Theoretical Frameworks to Understand DCD

This section has used the CMOP-E model to illustrate the multifaceted nature of DCD and how it impacts occupational participation and engagement. It has highlighted that whilst all children with DCD have difficulties with their motor skills, the manifestation of these difficulties and the impact that these have on their lives is not universal but the result of a dynamic interaction between the person, the occupation and environment.

2.5. Diagnostic Procedures and Assessment Tools

Due to the complex nature of DCD and the lack of an individual causal mechanism, International Guidelines for DCD have been created which provide guidance regarding the appropriate assessment and diagnosis of the condition. Whilst both the DSM-5 and ICD-11 have individual diagnostic criteria for Developmental Coordination Disorder (listed as 'Developmental Motor Coordination Disorder' in the ICD-11), the International Guidelines for DCD created specific diagnostic criteria (Table 2.2.) to minimise any differences between the two and create unified international diagnostic criteria. These criteria closely align with those outlined in the DSM-5 (American Psychiatric Association, 2013) typically used within the U.K. and the most commonly applied criteria in research prior to the International Guidelines for DCD (Table 2.3). According to these criteria the primary characteristic of DCD is an impairment in motor skills which is significant enough to interfere with participation in everyday activities (criteria Ⅰ and Ⅱ). These motor difficulties cannot be better accounted for by another medical condition, neurological impairment or any background, cultural or psychological factor (criterion Ⅲ) and the onset of motor difficulties must be within childhood (criterion Ⅳ).

Table 2.2.

International Guidelines for DCD; Recommendation 3: DCD diagnostic criteria (Blank et al., 2019:p15)

Ⅰ	The acquisition and execution of coordinated motor skills is substantially below that expected given the individual's chronological age and sufficient opportunities to acquire age-appropriate motor skills.
Ⅱ	The motor skill deficit described in criterion I significantly and persistently interferes with the activities of everyday living appropriate to chronological age (e.g. self-care and self-maintenance and mobility) and impacts upon academic/school productivity, prevocational and vocational activities, leisure and play
Ⅲ	The motor skill deficits are not better accounted for by any other medical, neurodevelopmental, psychological, social condition, or cultural background.
Ⅳ	Onset of symptoms in childhood (although not always identified until adolescence or adulthood).
Comment	Criterion I: The symptoms of DCD may include slowness and/or inaccuracy of motor skills performed in isolation or in combination.

Table 2.3.

DSM-5 Diagnostic criteria for Developmental Coordination Disorder 315.4 (F82) p. 74

A	The acquisition and execution of coordinated motor skill is substantially below that expected given the individual's chronological age and opportunities for skill learning and use. Difficulties are manifested as clumsiness (e.g. dropping or bumping into objects) as well as slowness and inaccuracy of performance of motor skills (e.g. catching an object, using scissors or cutlery, handwriting, riding a bike, or participating in sports).
B	*The motor skills deficit in Criterion A significantly and persistently interferes with activities of daily living appropriate to chronological age (e.g. self-care and self-maintenance) and impacts academic/school productivity, prevocational and vocation activities, leisure, and play.*
C	*Onset of symptoms is in the early developmental period.*
D	*The motor skill deficits are not better explained by intellectual disability (intellectual developmental disorder) or visual impairment and are not attributable to neurological condition affecting movement (e.g., cerebral palsy, muscular dystrophy, degenerative disorder).*

A diagnosis of DCD should be made by professionals qualified to apply the diagnostic criteria (Blank et al., 2019). This will often be a multidisciplinary team including a medical doctor and an occupational therapist and/or physiotherapist (Harris et al., 2015). Whilst the DSM-5 diagnostic criteria state that motor difficulties must be present within the early developmental period (criterion C) a diagnosis of DCD before the age of five is not recommended (Blank et al., 2019). This is due to the non-linear development and variability observed in skill acquisition both within standardised tests and activities of daily living for children below the age of five (Blank et al., 2019; Darrah et al., 1998, 2003). The International Guidelines also provide information on how the DCD criteria can be operationalised and this is summarised below, followed by descriptions of the range of measures frequently used with children.

i) The presence of a significant motor difficulty is confirmed by a score at or below 1 standard deviation from the mean on a standardised test of motor skills. An interview with the parent/carer can be used to confirm that sufficient opportunity has been provided to acquire age appropriate skills.
ii) Questionnaires for parents/carers and/or teachers are often used to confirm that motor difficulties described in criterion Ⅰ have a significant impact on daily life.
iii) An interview with the parents/carers and, when in clinical settings, a medical examination confirms that motor difficulties are not better explained by a physical, neurological intellectual impairment.
iv) An interview with the parent/carer can confirm the onset of symptoms in early childhood.

2.5.1. Criterion Ⅰ

Whilst difficulties with motor skills are the primary characteristic of DCD there is considerable individual variation in the pattern and presentation of these difficulties between children. Children can differ in the overall severity of their motor difficulties, as well as in the pattern of motor difficulties experienced (e.g. primarily fine motor difficulties or difficulties with gross motor skills) (Green et al., 2008). Standardised assessment can provide evidence that motor difficulties meet the threshold for a DCD diagnosis (criterion Ⅰ) and also provide a comprehensive profile of a child's motor performance across a range of motor domains.

The Movement Assessment Battery for Children 2nd Edition (MABC-2) Test (Henderson et al., 2007) is the most widely used and robust test of motor performance in children with DCD. It includes eight tasks to assess the areas of manual dexterity, aiming and catching, and balance for children aged three – sixteen years. It has UK norms and is widely used in English speaking countries and has been published in 10 additional languages (Blank et al., 2019). It has good to excellent test re-test reliability and is recommended in the International Guidelines for DCD. The second most popular standardised assessment of motor performance is the Bruininks-Oseretsky Test of Motor Proficiency 2nd edition (BOT-2) (Bruininks & Bruininks, 2005). The BOT-2 has 53 task items that assess a wide range of motor skills such as: precision, coordination, speed and dexterity of upper limbs, the speed of response, visual-motor control, bilateral movements, balance, running, general agility and strength. The BOT-2 has norms for people aged four to twenty one years in the US, Austria and Switzerland and norms from the ages of four to fourteen years in Germany. Separate norms are provided for males and females. Excellent reliability has been reported and fair-to-good agreement has been found between the BOT-2 and MABC-2 Test (Blank et al., 2019). However the US (English version) BOT-2 has been found to have lower sensitivity than the MABC-2, therefore it is not recommended in countries where the MABC-2 can be used (Blank et al., 2019). Other standardised tests of motor skills have been used in DCD research, for example the McCarron Assessment of Neuromuscular Dysfunction (McCarron, 1997), however, this is not validated or recommended to provide support for the DCD diagnostic criterion Ⅰ (Blank et al., 2019; Brantner et al., 2009). Due to the variability in the severity and pattern of motor difficulties in children with DCD the International Guidelines for DCD provide guidance regarding threshold scores on standardised assessments to evidence the presence of a significant motor difficulty (criterion Ⅰ). This is set at one standard deviation below the mean (the 16th percentile/standard score of ≤ seven) on the total test score.

2.5.2. Criterion Ⅱ

To provide evidence that the motor difficulties identified in criterion Ⅰ have an impact on everyday life (criterion Ⅱ) parent/carer and teacher questionnaires have been developed. The two most commonly used parent/carer and teacher questionnaires are the MABC-2 Checklist (Henderson et al., 2007) and the Developmental Coordination Disorder Questionnaire (DCDQ) (Wilson et al., 2009). These questionnaires ask about the performance of everyday activity related to underlying motor skills (e.g. washing and drying hands). The DCDQ is a parent/carer questionnaire and is the most frequently validated questionnaire in the literature (Blank et al., 2019). Its sensitivity in correctly identifying children with DCD is 84.6% and it has a moderate correlation to the MABC-2 Test (Henderson et al., 2007) (.55) (Wilson et al., 2009). The MABC-2 Checklist has been standardised using teacher responses and has been found to discriminate between children with and without DCD and showed moderate correlations to the MABC-2 Test (.38) (Schoemaker et al., 2012). Moderate correlations have also been found between the DCDQ and MABC-2 Checklist (0.36) (Schoemaker et al., 2012). This could reflect the fact that the questionnaires assess similar but slightly different aspects of motor performance. The DCDQ is designed as a screening measure whereas the MABC-2 Checklist provides a profile of performance and describes the nature of the movement difficulty. The moderate correlations between the two questionnaires could also highlight variability between parent/carer and teacher ratings of the same child. Variability between parent/carer and teacher raters has been found frequently in behavioural questionnaires (De Los Reyes & Kazdin, 2005).

2.5.3. Criteria Ⅲ and Ⅳ

Typically, for research purposes, a parent/carer interview confirms the absence of neurological or intellectual impairment or a medical condition which could better explain the motor difficulties. A standardised test of intelligence is sometimes used to rule out intellectual disability (Harris et al., 2015) or a shorter measure that correlates with intelligence such as the British Picture Vocabulary Scale 3rd edition (BPVS-3) (Dunn et al., 2009) (Prunty et al., 2016a). However, within the International Guidelines for DCD a history of normal school performance would negate the need for further intelligence testing. In clinical practice a medical doctor would also perform physical examinations to rule out neurological or sensory causes of motor difficulties (Blank et al., 2019). Physical disabilities such as arthritis, neurological conditions such as Cerebral Palsy, Muscular Dystrophy or acquired brain injury and major sensory impairments such as blindness would all exclude an individual from a DCD diagnosis as they would better explain the motor difficulties experienced. There are, however, some conditions for which there is debate surrounding whether a DCD diagnosis can co-occur. It has been argued, for example, that Join Hypermobility Syndrome would exclude a child from a DCD diagnosis as this laxity within the joints may provide a better explanation for the motor difficulties. However, Jelsma et al. (2013) found that whilst joint hypermobility in children with DCD was associated with a greater degree of motor difficulty, this was not true for joint hypermobility in the general population. This suggests that motor difficulties are not caused by joint hypermobility, but that joint hypermobility may exaggerate already existing motor difficulties. The International Guidelines for DCD also note that medical status such as potential joint problems and obesity should be included in the examination, however, Joint Hypermobility Syndrome is not explicitly listed as a condition which would exclude a diagnosis of DCD. The DSM-4 (American Psychiatric Association, 2000) previously excluded a DCD diagnosis in individuals with Autism Spectrum Condition (ASC), however, this has been revised in the latest edition DSM-5 (American Psychiatric Association, 2013) and dual diagnoses are now permitted for these conditions. Interviews are also used to confirm the early onset of symptoms (Blank et al., 2019). Whilst the onset of symptoms are in the early developmental period, children with DCD do develop early motor milestones such as independent sitting (Barnett et al., 2019). The trajectory of motor development for children with DCD is varied, some children experience consistent difficulties throughout childhood others show patterns of difficulty which change over time (Barnett et al., 2019). Evidence of motor difficulties in the early developmental period are evidenced by difficulties and delays in mastering occupationally focused milestones such as cutlery use or ball skills.

2.6. Common Co-occurring Difficulties with DCD

The CMOP-E model considers the physical, cognitive and affective aspects of an individual and how these effect occupational participation and engagement. Whilst the primary characteristic of DCD is a motor difficulty, individuals with DCD have also been reported to have cognitive and affective difficulties occurring more commonly than typically developing peers (Blank et al., 2019; Wilson et al., 2013). In some cases, these difficulties meet the severity for multiple diagnoses. There is strong evidence that DCD frequently co-occurs with other neurodevelopmental disorders such as Autism Spectrum Condition, Attention Deficit Hyperactivity Disorder, Developmental Language Disorder and Developmental Dyslexia (Blank et al., 2019). The co-occurrence rates are so high that DCD occurring in isolation is less common than it is occurring in the presence of at least one other neurodevelopmental disorder (Kirby et al., 2014). The high frequency of co-occurrence between these disorders has led to debate that these conditions are all varying manifestations of a single disorder (Cairney, 2015). The term 'Atypical Brain Development' has been suggested to replace the individual diagnostic labels currently used (Dewey & Bernier, 2016; Gilger & Kaplan, 2001; Kaplan et al., 1998). However, this is not recommended by the International Guidelines for DCD, DSM-5 (American Psychiatric Association, 2013) or ICD-11 (World Health Organization, 2018). Furthermore, even researchers who advocate for the use of the term Atypical Brain Development acknowledge that DCD is a 'well validated syndrome which is demonstrable in many populations' (Kaplan et al., 1998, p. 485). Those that argue for the use of Atypical Brain Development believe that it would be beneficial for demonstrating the overlap between the conditions and would suggest a shared underlying causal mechanism (Kaplan et al., 1998). It should be noted that often research investigating the co-occurring difficulties of individuals with DCD has not applied a full diagnostic assessment for each developmental disorder, for example using only a motor measure rather than the full DCD diagnostic criteria or using only measures of spelling or reading but not the full diagnostic criteria for developmental dyslexia.

2.6.1. Executive Function Difficulties

Executive Function difficulties have been mentioned previously as a potential underlying mechanism for DCD (section 2.4.1.2.). However, it is unknown if Executive Function difficulties are an underlying mechanism or a co-occurring difficulty (Blank et al., 2019). Executive Function difficulties are widely reported in children with DCD (Blank et al., 2019; Wilson et al., 2017; Wilson et al., 2013). Difficulties have been found across a wide range of tasks including traditional lab-based tasks, tasks adapted to involve emotions ('Hot Executive Function') and also within questionnaires and tasks which aim to replicate everyday life situations (Wilson et al., 2017). Difficulties with Executive Function in DCD are self-reported by adolescents with DCD as a primary area of concern impacting occupational performance and participation to a greater extent than their motor difficulties

(O'Dea & Connell, 2016). However, further research is needed which examines Executive Function in more detail in individuals with DCD as there is a lack of consistency in the findings across studies and a range of methodological limitations. This impacts the ability to draw firm conclusions regarding the nature of Executive Function performance in children with DCD. This will be discussed in further detail in chapter three.

2.6.2. Inattention and Hyperactivity

Inattention and hyperactivity has been widely reported to co-occur with motor difficulties with rates of 50% and higher depending on the measurements used and whether the sample was population or clinical (Green et al., 2006; Kadesjo & Gillberg, 1998; Miyahara et al., 2001). Kadesjo and Gillberg, (1998) in a population based study of seven year olds in Sweden found that 47% of those that met the criteria for ADHD also met the criteria for a diagnosis of DCD. Miyahara et al. (2001), within a clinical sample of children with hyperactivity, found motor skills below the 5th percentile in 35-55% of children, with percentages varying according to the source of the sample recruitment (school, support group or hospital), although this variance between the samples was not significant. Green et al. (2006), using the hyperactivity inattention scale from the Strengths and Difficulties Questionnaire (SDQ) (Goodman & Goodman, 2009) with a clinical sample of children with DCD, found high rates of hyperactivity and inattention as rated by parents/carers on the SDQ (57% with ‘significant’ and 21% with ‘borderline’ scores). High SDQ hyperactivity scores for children with DCD have also been confirmed within other studies (Crane et al., 2017).

2.6.3. Language and Literacy Difficulties

Language and motor difficulties also frequently co-occur; it has been reported that 32.3% of children with specific language impairment (now referred to as Developmental Language Disorder) met the diagnostic criteria for a DCD diagnosis. Furthermore, those with a dual diagnosis experienced poorer outcomes across a range of measures such as quality of life, compared to those with Developmental Language Disorder only (Flapper & Schoemaker, 2013). Higher rates of motor difficulties have been reported by Rintala et al. (1998) who found that 71% of children with Developmental Language Disorder had scores at or below the 16th percentile on a standardised assessment of motor skills. Literacy difficulties have also been found to co-occur with motor difficulties. Writing and spelling difficulties have been reported in English speaking children with DCD when compared to typically developing peers (Dewey et al., 2002; Prunty et al., 2016a) as well as difficulties with reading (Dewey et al., 2002). However, no significant difference in reading ability was found in children with DCD in a Taiwanese study using the Chinese Reading Achievement Test (Cheng et al., 2011). This suggests that reading difficulties in children with DCD could be the result of a perceptual deficit which is not present when using the symbols of the Chinese language (Blank et al., 2019). Iversen et al. (2005) found in a sample of children with severe dyslexia from Norway, that over 50% also had motor skills below the 5th percentile on a standardised test. However, in a UK study children with dyslexia were not found to differ significantly to typically developing peers on manual dexterity tasks (Sumner et al., 2013). It is important to note that neither Iversen et al. (2005) nor Sumner et al. (2013) sought to meet the full DCD diagnostic criteria.

2.6.4. Social Emotional Difficulties

Difficulties with emotional control and peer relationships have been widely reported in children with DCD (Blank et al., 2019; Crane et al., 2017; Green et al., 2006). However, there is debate regarding whether these are co-occurring difficulties or a secondary consequence of DCD (Blank et al., 2019). DCD and ASC have been reported to frequently co-occur, with 78% of children with ASC experiencing motor difficulties in line with those experienced in DCD (Green et al., 2009). Children with DCD also have an increased risk of mental health issues such as anxiety and depression (Blank et al., 2019; Cairney, Veldhuizen, et al., 2010; Piek & Rigoli, 2015; Pratt & Hill, 2011). Pratt and Hill, (2011) found in their sample of children aged six to fifteen years with DCD (and no co-occurring conditions) that nearly 30% met clinically significant levels of social phobia. It has been argued that these higher rates of mental health and social issues could be as a consequence of higher rates of bullying and poor self-concept related to motor difficulties (Blank et al., 2019). Children with DCD have been found to rate their self-esteem as lower than both their typically developing peers and peers with major physical disabilities such as Cerebral Palsy and Spina Bifida (Miyahara & Piek, 2006). One explanation for this finding is that the difficulties children with DCD experience are often misinterpreted as behavioural problems in a manner unlikely to happen to their peers with greater physical disabilities (Piek & Rigoli, 2015). These findings are important, not just because low self-esteem has been found to predict anxiety and depression in both adults and children, but also because it is related to lower participation and quality of life (Blank et al., 2019; Sowislo & Orth, 2013).

2.6.5. Physical Inactivity

Individuals with DCD have also been found to have increased rates of sedentary behaviour (Cermak et al., 2015) and decreased participation in social activities such as physical playground games and sports (Smyth & Anderson, 2010). In large longitudinal studies children with DCD have also been found to have a higher Body Mass Index, larger waist circumferences and an increased chance of meeting the threshold for overweight and obesity compared to their typically developing peers; these are risk factors for life long conditions such as cardio-vascular disease (Cairney, Hay, et al., 2010; Joshi et al., 2015). Whilst it has previously been reasoned that body compositional differences in children with DCD could be a secondary consequence of DCD related to the lower levels of physical activity, Joshi et al. (2015) could not account for differences in Body Mass Index and waist circumference in children with DCD with differences in physical activity levels (Joshi et al., 2015). Children with DCD have also been found to have lower cardio-respiratory fitness which had also previously been considered to be related to the lower levels of physical activity (Faught et al., 2005). However, in a five year longitudinal study Cairney et al. (2017) found that cardio-respiratory fitness declined more steeply in children and adolescents with DCD compared to those with typical development and that engagement in physical activity explained only a small proportion of the difference found. This suggests that high Body Mass Index and lower cardio-respiratory fitness may be co-occurring with, rather than a secondary consequence of DCD.

2.7. Impact on Everyday Life

Many possible overlapping difficulties interact with motor performance for children with DCD which can have a negative impact on occupational engagement and participation across many areas of an individual's everyday life. The interaction between difficulties with Executive Function and motor skills in everyday life are considered here using the CMOP-E model. The CMOP-E divides occupational and participation challenges into three broad areas of self-care, productivity and leisure (Townsend & Polatajko, 2007). Profiles of the range and extent of the difficulties experienced with DCD can vary between individuals as can activity preferences, therefore the impact on everyday life can vary. Here a selection of common occupations (tasks/activities) which are often affected are outlined. In the area of self-care, difficulties with motor skills can negatively affect a person's ability to carry out tasks such as using cutlery, tooth brushing, styling hair, applying make-up and dressing, including manipulating zips and buttons (American Psychiatric Association, 2013; Rosenblum & Engel-Yeger, 2014). Difficulties with Executive Function together with motor difficulties, impact on self-care tasks leading to difficulties with sequential activities such as organising clothes and cooking meals. Within the area of productivity children are frequently reported to experience difficulties meeting the handwriting demands of school (Prunty et al., 2014) and adults can have difficulties with tasks that require speed and accuracy (American Psychiatric Association, 2013) (e.g. minute taking and physical labour work such as construction). Difficulties with Executive Function, such as the organisation of belongings, are also frequently reported to disrupt work and school (O' Dea & Connell, 2016; Green & Payne, 2018) as well as tasks which have high Executive Function and motor demands simultaneously such as driving (de Oliveira & Wann, 2012). In leisure activities, the motor difficulties of children with DCD often lead to less participation in games such as skipping, ball games, craft activities and bike riding (Harris et al., 2015; Smyth & Anderson, 2010) and adults with DCD are reported to engage less frequently in team sports (Rosenblum & Engel-Yeger, 2014). Children with DCD have also been reported to have lower levels of social engagement due to both their motor difficulties and associated areas of difficulty (e.g. poor self-esteem) (Chen & Cohn, 2003; Piek & Rigoli, 2015). Difficulties with Executive Function could also potentially hinder social activities, for example when holding a conversation working memory is needed to remember what has been said and to reply appropriately and Inhibition is required to not interrupt others. Furthermore, in adolescence and adulthood difficulties with Executive Function could hinder a person's ability to initiate a plan for a social activity e.g. a group cinema trip, or birthday celebration.

2.8. Interventions for DCD

Camden et al. (2015) in a scoping review identified two overarching best practice guidelines for intervention for children with DCD. The first centred on organizing services to meet the needs of children including increasing awareness of DCD. The second guideline was centred around working collaboratively to provide evidence-based services. This includes the integration of family and child views and delivering occupationally centred interventions aimed at increasing participation and the prevention of potential secondary consequences such as internalising symptoms and low self-esteem.

Intervention can be structured around the CMOP-E model. Using the example of bike riding, some intervention strategies aim to develop personal factors such as developing the child's procedural ability to ride the bike (e.g. balance, leg rotation), others aim to make adaptations to the occupation (the activity of bike riding) such as removing the pedals from the bike when first learning to balance or using an adapted bike or tricycle. Other strategies aim to make adaptations to the environment such as practicing on a clear and even surface rather than in a busy park with lots of hills. Person, occupation and environmental interventions are often used together in a dynamic way to facilitate occupational participation and engagement. Within the therapeutic process intervention often follows an in-depth assessment of the functional areas of difficulty, enabling plans to be tailored to the individual's needs and motivations (Creek, 2003). Interventions are frequently delivered by occupational therapists (Kennedy-Behr & Rodger, 2019) and physiotherapists and psychologists are also often involved (Barnhart et al., 2003; Blank et al., 2019). Below a selection of interventions are discussed in relation to the CMOP-E areas of person, occupation and environment.

2.8.1. Person

At the level of the person, interventions can be divided into 'bottom-up' and 'top-down' approaches (Kennedy-Behr & Rodger, 2019). 'Bottom-up' or 'process orientated' approaches aim to achieve activity level goals (e.g. tying laces) through the practice and development of underlying skills (e.g. finger strength) (Schaaf & Mailloux, 2015). 'Top-down' approaches aim to achieve activity level goals (e.g. tying laces) through explicit teaching or guided problem solving of the task itself (e.g. teaching the steps to tie laces or asking the child to evaluate and modify their own lace tying technique) (Kennedy-Behr & Rodger, 2019). In a systematic review of interventions to improve motor skills in children with DCD, Smits-Engelsman et al. (2013) found stronger evidence for top-down approaches in comparison to bottom-up approaches. Top-down approaches are also recommended by the International Guidelines for DCD. The Cognitive-Orientation to daily Occupational Performance (CO-OP) approach is a top-down approach which was specifically developed for children with DCD (Polatajko et al., 2001). In this approach children use Executive Function skills to problem solve strategies to achieve their goals through a process of guided discovery (Polatajko et al., 2001). Other top-down approaches such as Neuromotor Task Training (Schoemaker et al., 2003) have greater explicit instruction and scaffolding from the therapist compared to CO-OP and arguably less Executive Function demands from the child. Whilst approaches such as the CO-OP and Neuromotor Task Training have good evidence of developing task performance, there is limited evidence of generalisability to other skills or an increase in participation in everyday life (e.g. joining a football club) (Smits-Engelsman et al., 2018).

2.8.2. Occupation

Interventions can also be targeted at the level of the occupation (task/activity); these interventions aim to adapt the occupation so that it is manageable at a person's current skill level. These intervention approaches are primarily focused on increasing participation. In children with DCD occupation level interventions sometimes involve physical adaptations to a task such as the use of adapted rulers, cutlery or scissors as well as adaptations to task instructions or demands (for example using thicker lines when cutting with scissors). Within physical education lessons interventions aimed at the level of the occupation could involve altering the size and weight of balls, and distance required for target practice or scoring (Hands & Parker, 2019). Grouping children based on their skill level also enables task demands to be differentiated allowing children to progress at a level appropriate to them. Creating roles, such as a referee or manager, within sporting events can also include children who may otherwise be left out (Hands & Parker, 2019). Task adaptations can also be made to support difficulties with Executive Function such as using written checklists which can be ticked off as parts of the task are completed (Ylviasker et al., 1987).

2.8.3. Environment

Environmental interventions are concerned with adapting environments to limit the barriers that children with DCD can experience. Environmental adaptations can involve the physical environment (for example spacing tables so that children can navigate the classroom more easily or providing designated locations for school equipment at home) as well as the social environment (such as the provision of extracurricular activities that are not affected by motor difficulties e.g. drama club, or non-competitive physical activity options). Educating parents/carers and teachers of the difficulties of children with DCD can also change how the child experiences their environment, and are recommended within best practice guidelines for intervention (Camden et al., 2015). This is because often the difficulties experienced by children with DCD can be misinterpreted as poor behaviour prior to diagnosis, particularly at school (Missiuna, Moll et al., 2006).

For intervention to be beneficial for individuals with DCD it is important to have a comprehensive understanding of the underlying difficulties they experience. This is because the same functional challenge (e.g. getting out of their chair at an inappropriate time in the classroom) could be due to different underlying causes (e.g. forgetting the instruction or difficulties with inhibiting this desire). Difficulties with motor skills are a core component of DCD and there is international agreement regarding how these should be assessed. However, the range and extent of difficulties with Executive Function and how these should be assessed has yet to reach consensus (Leonard & Hill, 2015). Furthermore, there is currently no evidence that difficulties with Executive Function that have been found for school aged children with DCD using performance tasks are also found within everyday life. Therefore, further research is needed which uses a broad range of assessments to examine if children with DCD have difficulties with Executive Function, as well as investigating if motor and Executive Function skills relate more broadly. This information can contribute to recommendations regarding the assessments that should be used with children with DCD to correctly identify areas of need in order to appropriately plan and evaluate intervention.

2.9. Summary

This chapter has provided an overview of DCD using the CMOP-E model. It described the condition, outlined some of the theoretical underpinnings, the diagnostic and assessment process, as well as the impact on everyday life, and interventions that can increase occupational performance and participation. Motor skills were highlighted as the core characteristic of the condition and Executive Function was highlighted both as a potential underlying mechanism for the condition and as a potential co-occurring difficulty. Executive Function was also discussed as a strategy used in intervention with individuals with DCD. This chapter briefly discussed the challenges of examining Executive Function in DCD. The next chapter will consider Executive Function in greater detail, considering theoretical frameworks, the developmental trajectory as well as commonly used assessment methods.

3. Executive Function

3.1. Introduction

In the previous chapter motor skills were highlighted as the core characteristic of DCD and Executive Function was highlighted both as a potential underlying mechanism for the condition and as a potential co-occurring difficulty. However, the understanding of the Executive Function skills of children with DCD and how Executive Function skills relate to motor skills more broadly is currently unclear. Executive Function has been defined as higher level thinking ability which enables self-regulation and goal directed behaviour (Best & Miller, 2010). These skills are necessary across many areas of life and difficulties can have far reaching consequences on participation and satisfaction in everyday life, both for the individual and also their families, teachers and peers (Sparrow & Hunter, 2012b). Despite the importance of Executive Function there is currently no consensus regarding its exact structure. Several distinct models have been proposed which differ in their definitions, some consider Executive Function as a unitary structure (Baddeley & Hitch, 1974; Norman & Shallice, 1986), others consider it to consist of diverse individual components (Lehto, 1996), and others consider it to be a mix of this unity and diversity (Miyake et al., 2000). Up to 30 individual components have been reported throughout the literature (Kluwe-Schiavon et al., 2017), the most commonly reported are Working Memory, Mental Flexibility and Inhibition (Diamond, 2013).

The main focus of this research is on one of the components of Executive Function, Inhibition, in children aged six to ten years old. Research has found that children with DCD have difficulties with Inhibition (Michel et al., 2018; Sartori, Valentini, Fonseca, 2020), however, results across studies are inconclusive, and Inhibition has not been studied as extensively as other components of Executive Function such as Working Memory (Alloway, 2007, 2011). Developing the understanding of the Inhibition skills of children with DCD and how Inhibition and motor skills relate can lead to a greater theoretical understanding of the condition. Furthermore, clinically this could result in children with DCD receiving more comprehensive clinical assessments and interventions. Inhibition skills in childhood are positively associated with better physical and mental health, better educational attainment and reduced engagement in drug taking behaviours in adulthood (Moffit et al., 2011).

In everyday life Executive Function components are used together therefore isolating behaviours caused by Inhibition specifically can be difficult. Furthermore, it can also be challenging to clearly distinguish between Inhibition and other cognitive processes such as sustained attention in everyday life. Despite this challenge, behaviours which are typically associated with successful Inhibition skills in everyday life for children include ignoring distracting information to remain focused on a task. For example, a teacher may instruct some children in their class to complete a maths task, while others engage in another activity. If a child struggles to inhibit a response to join in the other activity they will fail to complete the set task. Such behaviour can have a negative impact on learning, and lower skills may affect the child's self-esteem. These difficulties with Inhibition may also be perceived by the teacher as intentional 'naughty' behaviour, possibly leading to disciplinary action such as detention rather than support. Evidence has been found that children as young as six can internalise teachers' negative perceptions which can in turn negatively affect their self-esteem (Doumen et al., 2011) and individuals with DCD have been found to have higher rates of internalising symptoms compared to typically developing peers (Omer et al. 2019). Chapter two (section 2.8.) highlighted that preventing poor self-esteem and internalising symptoms in children with DCD is a priority for intervention (Camden et al., 2015). Therefore, furthering the understanding of Inhibition in children with DCD could help to prevent this secondary consequence.

The aim of this research is to further the understanding of the Executive Function and Inhibition specific skills of children with and without DCD, and to examine relationships between Inhibition and motor skills. One of the challenges of drawing firm conclusions from previous research on this topic is a lack of clarity and consistency in how Executive Function and Inhibition have been defined and measured. Therefore, this chapter focuses on reviewing and discussing a selection of models of Executive Function. It also outlines the developmental trajectory of Executive Function and considers the validity of investigating Inhibition in isolation in children of primary school age (six to ten years). Definitions, and the individual developmental trajectory of Inhibition are also outlined. Aspects of the underlying neurobiology of Executive Function are considered and the relevance for motor control is discussed where appropriate. Finally, this chapter will consider different methods for the assessment of Executive Function and Inhibition specifically, discussing the strengths and limitations of each approach.

3.2. Theories of Executive Function

Although a wide range of models of Executive Function have been described in the literature, one of the most commonly applied in research is the Unity and Diversity model (Miyake et al., 2000). This considers Executive Function as a set of individually distinguishable components which share underlying commonality. This model has been informed by a range of earlier models which either considered Executive Function as a unitary construct or as individual components such as working memory. Therefore, this section will consider a range of models of Executive Function which have led to the current Unity and Diversity model.

The earliest work into Executive Function primarily concerned adults with frontal lobe damage (Sparrow & Hunter, 2012a). The earliest case of impairment to frontal lobe functions is deNobele in 1835, however, the best known case in which the pathology and aetiology of the damage is known is Phineas Gage described by Harlow in 1848 (Lyketsos et al., 2004). Following serious damage to his left frontal lobe, Phineas was reported to be a ‘changed man’, he was unable to return to his work as a foreman and the accident was described as having a profoundly negative impact on his behaviour and social ability (Lyketsos et al., 2004). Luria in 1969 also describes a condition called ‘the frontal lobe syndrome’ effecting patients with frontal lobe damage. Although he did not use the term Executive Function, Luria outlined symptoms typical to what would currently be described as deficits with Executive Function, for example difficulties with completing complex tasks, planning and inhibiting inappropriate responses (Luria, 1969; Sparrow & Hunter, 2012a; Zelazo et al., 2008). The terms ‘frontal lobe’ and ‘executive’ have previously been used interchangeably (Sparrow & Hunter, 2012a). However, there is now evidence that, whilst the frontal lobes, in particular the prefrontal cortex, play a central role in Executive Function, they rely on distributed neural networks which involve multiple brain regions which are also involved in the function of other domain areas such as motor skills. Brain regions such as the cerebellum, dorsolateral prefrontal cortex and connecting structures, including the basal ganglia, have been found to be crucial for both Executive Function and motor skills, and co-activation of these regions have been found during both Executive Function and motor tasks (Abe & Hanakawa, 2009; Diamond, 2000; Hanakawa, 2011). Therefore the anatomical term ‘frontal lobe’ is not synonymous with the functional term ‘executive’ (Miyake et al., 2000). This also suggests Executive Function skills may also be associated with other performance areas such as motor skills.

Several theories have been put forward to define the structure and function of Executive Function. Bronowski, in a lecture in 1967, outlined a theory to explain why human language differed from communication in other species (Bronowski, 1967, 1977). Whilst this theory focused on language, it outlined what are now thought of as key elements of Executive Function (prolongation, separation of affect, internalization and reconstitution) (Barkley, 1997a, 1997b). Prolongation refers to using previous knowledge to inform future decisions whilst considering the present situation; this aligns with what is currently considered as Working Memory. Bronowski’s theory also emphasised inhibiting initial responses to decode meaning from affect (separation of affect); delaying initial responses to consider alternatives (internalization) and analysing the emotion and language of a message prior to forming an appropriate response (reconstitution) (Barkley, 1997a, 1997b).

Norman and Shallice (1980) proposed a theory explaining voluntary action which included an executive monitoring system called the Supervisory Attentional System (SAS). This theory proposes that actions are the consequence of the activation of appropriate schemas (action and thought sequences which dictate behaviour). Contention scheduling implements frequently used schemas for automatic tasks; for novel tasks and tasks with greater complexity the SAS exerts control over contention scheduling, inhibiting more automatic schemas in favour of alternative weaker ones (Norman & Shallice, 1986). Failures in the SAS can result in ‘action slips’, when the SAS fails to override more automatic schemas (e.g. putting milk into a black coffee) and perseveration in which a person proceeds with a planned response despite a change in circumstance (Andrade & May, 2004).

The term ‘executive’ was first used in the literature in Baddeley and Hitch’s model of the ‘central executive’ (1974). This model explains Working Memory by describing a ‘central executive’ with limited attentional capacity. The central executive controls the organisation of information into two slave systems which store information for a short period: the Phonological Loop, which stores verbal data and the Visuo-spatial Sketchpad which stores visuo-spatial data. Influenced by Norman and Shallice’s (1986) work regarding the Supervisory Attentional System, previously outlined, Baddeley reviewed their original theory and added a fourth component: ‘the episodic buffer’ (Baddeley, 2000). The episodic buffer is also a slave system controlled by the central executive, it combines information from the Phonological Loop, Visuo-spatial Sketchpad and Long Term Memory systems enabling information to be chunked together and perceived as a whole (e.g. an object’s movement and the associated sound or grouping new information based on prior knowledge) (Gathercole, 2009).

In 1997 Barkley criticised Baddeley and Hitch’s (1974) central executive for creating a black box within the brain. This is because the model did not explain how the ‘central executive’ works (Barkley, 1997a, 1997b); this criticism has also been levied at the SAS model (Sparrow & Hunter, 2012a). Aiming to address the criticism of the black box, Barkley created a model to explain Executive Dysfunction in Attention Deficit Hyperactivity Disorder. This model suggests a linkage between Inhibition and four other components of Executive Function (Working Memory, Internalisation of Speech, Self-Regulation of Affect–Motivation-Arousal and Reconstitution). He proposed that all four of these Executive Function components rely on Inhibition for their own performance and that they all influence motor control systems (Barkley, 1997a, 1997b). Whilst Barkley referred only to ‘Inhibition’, his Inhibition concept encompasses three aspects of Inhibition which would now be referred to distinctly as:

- Response Inhibition, the ability to override automatic but unhelpful responses in favour of a less automatic response (Nigg, 2000)
- Interference Control, the ability to be able to ignore distracting information (Nigg, 2000)
- Action Cancellation, the ability to stop an ongoing response (He et al., 2018).

However, Barkley (1997a) acknowledged that the three Inhibition elements may be separable processes. Barkley's model expands on the earlier ideas of Bronowski (1967, 1977) that Inhibition is an underlying support mechanism for other abilities and expands on the idea to include the influence on motor control (Sparrow & Hunter, 2012a). Whilst Barkley's model has been criticised for pertaining solely to individuals with Attention Deficit Hyperactivity Disorder and omitting some components of Executive Function (e.g. Mental Flexibility), it provides a useful approach to investigate the interaction of Executive Function and other cognitive processes (Sparrow & Hunter, 2012a).

More recent work provides evidence that Executive Function has distinct components which have shared underlying commonality (Miyake et al., 2000; Miyake & Friedman, 2012; Niendam et al., 2012). Miyake et al. (2000) were concerned with investigating whether Executive Function was a unitary concept, as suggested by the earlier models (particularly the Central Executive and SAS), or whether Executive Function consists of separable components (Miyake et al., 2000). Evidence of separability is found from research using test batteries of Executive Function components finding low or non-significant correlations among tasks and multiple separable factors rather than one unitary factor (Huizinga et al., 2006; Lehto, 1996), differing patterns of difficulty observed in patients with frontal lobe damage (Rabinovici et al., 2015) and differing developmental trajectories for individual components (Huizinga et al., 2006). However, Miyake et al. (2000) argued that methodological and data analysis limitations in previous studies resulted in an inability to draw firm conclusions. Miyake et al. (2000) used latent variable analysis to examine relationships between three frequently postulated components of Executive Function: 1) shifting between tasks or mental sets ('Shifting'), 2) updating and monitoring the contents of working memory ('Updating), 3) inhibition of prepotent responses ('Inhibition'). Within current research on Executive Function the concept of 'Shifting' is more commonly referred to as 'Mental Flexibility' (Diamond, 2013), 'Updating' as 'Working Memory' (Diamond, 2013) and the Inhibition Miyake et al. (2000) investigated most closely aligns with Response Inhibition (Laloi et al., 2017). Other frequently cited components of Executive Function include Planning and Organisation, however, these have been argued to be multifaceted skills of greater complexity than those investigated by Miyake et al. (2000) (De Luca & Leventer, 2008; Garon et al., 2008). Miyake et al. (2000) chose these three components of Executive Function because they had precise definitions and pre-established measures which uniquely tapped into each component, limiting task impurity issues (Miyake et al., 2000). Many measures of Executive Function were also thought to assess the interaction between these three components of Executive Function and therefore developing a thorough understanding of the relationship between each was considered important (Miyake et al., 2000).

These three components of Executive Function (Shifting'/'Mental Flexibility'; 'Updating'/'Working Memory'; Inhibition/Response Inhibition) are still the most commonly cited to date and often referred to as 'core' or 'central' components of Executive Function (Diamond, 2013; Lemire-Rodger et al., 2019; Leonard & Hill, 2015). In their research with college students, Friedman and Miyake, (2004) and Miyake et al. (2000) found evidence that the three components of Executive Function were individually distinguishable but that they were also moderately correlated, sharing some commonality; this provides evidence of both unity and diversity within Executive Function. In later studies Friedman et al. (2008) and Friedman et al. (2011) found that when accounting for the unity which they call 'Common EF' factor, specific variance remained for Mental Flexibility and Working Memory but not Inhibition (which correlated perfectly with 'Common EF'). Friedman et al. (2011) suggested that this finding had two possible explanations: firstly that Inhibition is the underlying mechanism for the other Executive Function components, as suggested by Bronowski's theory of language (1967, 1977) and secondly that Inhibition relies heavily on processes which are common to all components of Executive Function, such as maintaining task goals and task related information. Research using both behavioural (Fisk & Sharp, 2004) and neuroimaging (Lemire-Rodger et al., 2019; Niendam et al., 2012) techniques has continued to provide evidence for the unity and diversity of Executive Function. However, disagreement remains regarding what the 'Common EF' factor represents. Findings from Lemire-Rodger et al. (2019) suggest it is Working Memory, and Dajani and Uddin, (2015) argue that it is Mental Flexibility. Alternatively, due to the different tasks used across the research studies, the 'Common EF' factor could represent an ability that is common to all of these tasks rather than one component of Executive Function specifically (Miyake & Friedman, 2012).

Miyake et al.'s (2000) Unity and Diversity model and the additional research which supports it has been conducted using traditional Executive Function tasks that require abstract reasoning and problem solving. However, a distinction has been made within the literature between ‘cold’ Executive Function tasks, such as those used by Miyake (2000) and ‘hot’ Executive Function tasks which involve tasks that have emotional salience or motivational significance (Sparrow & Hunter, 2012a). Research shows that tasks that traditionally assess cold Executive Function that have been adapted to add emotional salience (e.g. using pictures of facial expression) show differing responses and patterns of difficulty within clinical groups (Rahimi-Golkhandan et al., 2016). Some DCD research which has investigated ‘hot’ Executive Function will be discussed in chapter four, however, the research presented here focuses on tasks that use ‘cold’ Executive Function. This is because there is not currently a clear understanding of the Inhibition skills of children with DCD in non-emotionally salient conditions (see chapter four). It is important to gain this baseline understanding prior to adding in an additional level of complexity. Furthermore, while there is some agreement about how to measure aspects of ‘cold’ Inhibition, there is debate regarding how exactly ‘hot’ Inhibition can be measured. For example, Rahimi-Golkhandan et al. (2016, 2014) use happy and fearful faces in a Go/Nogo task to assess ‘hot’ Inhibition, whereas Thornton et al. (2018) use happy and sad faces in a Go/Nogo task without attempting to assess ‘hot’ Inhibition.

The research in this thesis uses the Unity and Diversity model of Executive Function (Miyake et al., 2000). This is due to the wealth of behavioural and neuroimaging research which supports this model and additional evidence that this model has also been found applicable for primary school aged children (five - ten years) (Messer et al., 2018), who are the focus of this research. Research regarding the development of Executive Function and the structural differences related to age will be discussed later in this chapter.

3.2.1 Theories of Inhibition

Inhibition is the ability to override automatic but inappropriate or incorrect responses as well as to resist interference which could cause distraction (Liu, Ziegler, Shi, 2015). Proficiency in Inhibition has been associated with cognitive, behavioural and social emotional competence as well as better school performance (Howard et al., 2014; Diamond, 2013). Difficulties with Inhibition specifically can result in impulsive behaviour and distractibility leading children to have difficulties maintaining focus on tasks. For children, Inhibition difficulties can often be misinterpreted as intentionally poor behaviour choices which can lead to disciplinary actions such as school detentions and removal from the classroom. Being viewed as 'naughty' can also negatively affect children's self-esteem and school experience (Cross, 2011; Missiuna, Gaines et al., 2006).

Inhibition is generally considered to consist of separate but interrelated processes rather than being a unitary construct, (Dempster, 1993; Friedman & Miyake, 2004; Nigg, 2000; van Boxtel et al., 2001). Nigg's (2000) taxonomy of Inhibition proposes four separate but related components of Inhibition:

- Behavioural/Response Inhibition (the ability to override automatic but unhelpful responses)
- Interference Control, (the ability to ignore task irrelevant information)
- Cognitive Inhibition (the ability to suppress thoughts)
- Oculomotor Inhibition, (the ability to control eye saccades).

Researchers do not always agree on the classification of the domains of Inhibition (Friedman & Miyake, 2004). For example, not all researchers differentiate between action cancellation tasks, that require the cancelling of an ongoing action and action restraint tasks that require the ability to withhold a strong response tendency (Sinopolia et al., 2011). However, it is widely acknowledged that there is a distinction between Response Inhibition and Interference Control (Laloi et al., 2017) with further research confirming differing patterns of brain activation for these two components (Brydges et al., 2012, 2013).

Experimental tasks of Response Inhibition and Interference Control differ due to task demands. A Response Inhibition task presents one dimension but has two competing responses (Laloi et al., 2017). An example of a Response Inhibition task is a go/nogo task in which a person must respond as quickly as possible to one stimulus (e.g. a yellow dot) but withhold responding to a another stimulus (e.g. a blue dot). An Interference Control task simultaneously presents two conflicting dimensions with only one relevant to the task (Laloi et al., 2017). An example of an Interference control task is a Stroop task in which a person is presented with a colour word printed in a different colour ink (e.g. the word red printed in blue ink), the responder must say the colour of the ink, not the colour of the word (e.g. blue). Using Event Related Potential (ERP) techniques Brydges et al. (2012) and Brydges et al. (2013) provided support for the separability of these two types of Inhibition in adults and children respectively as well as differing developmental trajectories (Brydges et al., 2013).

Assessments of Inhibition can differ in the response modality required, with some requiring a motor response and others a verbal response. The impact that this difference in response modality can have on assessment validity, particularly when used with individuals with conditions such as DCD, is considered later in this chapter. There has also been theoretical consideration of whether Inhibition of motor responses differs from Inhibition of verbal responses. Using an Exploratory Factor Analysis (EFA) Messer et al. (2018) aimed to assess verbal and motor Executive Function tasks hypothesising that the results would show separate factors for those tasks with a verbal response and those with a motor response but this was not supported. However, Messer et al. (2018) analysed performance across a range of Executive Function components using verbal and motor tasks for each component (e.g. Response Inhibition with verbal and motor response modalities). Therefore, these findings do not provide evidence that verbal and motor response modalities are identical. Instead the results suggest that any differences between response modality (verbal, motor) for the same Executive Function component are not as large as differences between the components (e.g. Response Inhibition and Working Memory).

Inhibition that requires a motor response has been further divided into Action Restraint (Inhibition of unwanted prepotent motor responses) and Action Cancellation (stopping an ongoing movement or cancelling a prepared movement) (He et al., 2018). The distinction between action restraint and action cancellation has also been supported with neuroimaging studies, suggesting that they rely on different brain regions (He et al., 2018). He et al. (2018) present the only research study to investigate action cancellation in a population of individuals with DCD. They found that adults with DCD performed more poorly on an action cancellation task than controls. The distinction between action restraint and action cancellation has not been investigated in children with DCD. Chapter four will outline the research investigating Inhibition and Executive Function in children with DCD in more detail.

3.3. Structure and Developmental Trajectory of Executive Function

This section will examine research related to the development of Executive Function from early childhood to early adulthood. Issues around the assessment of Executive Function will be considered in more detail later in this chapter. However, when considering the evidence for the development of Executive Function it is important to consider the lack of 'gold standard' or 'pure' assessments for any age but particularly for children (Anderson et al., 2008; Zelazo et al., 2008). Whilst there is sufficient evidence to provide a general description of the developmental progression of Executive Function, limitations in the assessment methods used make it difficult to understand development in detail (Anderson et al., 2008).

The development of Executive Function appears to follow a hierarchical pattern, with fundamental skills such as Working Memory coming 'online' prior to more complex and multifaceted skills such as Planning and Organisation (De Luca & Leventer, 2008; Garon et al., 2008). Rather than a linear progression, the maturation of Executive Function is better conceived as developmental spurts with large individual variance, which are highly influenced by environmental and social factors (De Luca & Leventer, 2008). There are parallels between observed Executive Function behaviours and the development of the frontal lobes, both of which are immature in young children, with an extended development into early adulthood (De Luca & Leventer, 2008). The frontal lobes develop in utero and are distinguishable at birth, however, they are very immature and largely unmyelinated (De Luca & Leventer, 2008). Myelination of the Pre Frontal Cortex, which is the area most central to Executive Function, is not complete until well into the third decade of life and is largely influenced by experience (De Luca & Leventer, 2008). Executive Function is one of the last cognitive functions to reach maturity and this protracted developmental period is necessary due to its complexity (De Luca & Leventer, 2008).

Historically, it was thought that Executive Function was not present in children (Golden, 1981) however, this was based on research that used tasks developed for adults. It is now believed that Executive Function is present even when children are very young but that development continues throughout childhood and into early adulthood (Huizinga et al., 2006). Diamond et al. (2003) found that children aged 12 months, when appropriately motivated by a reward, were able to successfully complete a task that taps into Working Memory (De Luca & Leventer, 2008). Evidence of successful Response Inhibition and Working Memory have also been found in children as young as seven and a half months using the A not B delayed response time task (Diamond, 1985). In this task, the tester hides an object in full view of the child in one of two locations, following a period of hiding the object in one location it is then hidden in the alternative location. Following a delay the child must then reach for the correct location of the item, inhibiting their previous habitual response (Diamond, 1985). This task shows age related gains in performance as evidenced by an increased tolerance in the delay between the object being hidden and the child's successful retrieval from one to two seconds in children aged seven and a half months (Diamond, 1985) to ten seconds in children aged five years (Espy et al., 2001; Espy et al., 1999).

Executive Function in children aged six years and lower has been found to align more closely to a unitary construct rather than a mix of the unity and diversity that is seen in older children and adults (Hughes et al., 2010; Wiebe et al., 2008). As children mature, the components of Executive Function develop increasing separability, although debate surrounds which factors are separable at which ages (Messer et al., 2018). In children aged six to twelve years a number of different factor structures have been suggested. Shing et al. (2010) investigated whether Working Memory and Inhibition were separable in children aged four to fourteen. They found that a single factor structure best accounted for the data for children aged four to eight but that a two factor structure was the best fit for children aged nine to fourteen years. Brydges et al. (2012) similarly found a single factor structure in children aged seven to nine years, when examining Inhibition, Working Memory and Mental Flexibility. In a longitudinal study using the same measures, Brydges et al. (2014) found that a single factor structure best explained the data at time point one when children had a mean age of eight years three months but a two factor structure fitted best at time point two when children were ten years three months. In contrast Xu et al. (2013) found evidence that a unitary structure best accounted for their data when considering Working Memory, Inhibition and Mental Flexibility in children aged seven to twelve years.

In a sample of children aged six to twelve years, Messer et al. (2018) found evidence of a two-factor model of Executive Function with Inhibition as a separable factor. Messer et al. (2018) argue that despite a range of different factor structures identified in the literature, the greatest evidence is for a multifactorial model of Executive Function between the ages of six and twelve. This is supported by evidence from Karr et al.'s (2018) systematic review which found the greatest evidence for a three-factor structure in children aged six to twelve years. Lehto et al. (2003) used exploratory and confirmatory factor analysis with children aged eight to thirteen years and discovered a three-factor interrelated model with Inhibition, Working Memory and Mental Flexibility (Shifting) factors. Wu et al. (2011) also found support of a three factor model in children aged seven to fourteen years. Huizinga et al. (2006), on the other hand, in a sample of individuals aged seven years to twenty one years, found evidence of two dissociable but moderately correlated factors of Executive Function: Mental Flexibility (Shifting) and Working Memory but no separate factor for Inhibition. It is possible that the wide age range used influenced these results (Garon et al., 2008). Furthermore, the three Inhibition tasks that were used by Huizinga et al. (2006) each assessed different aspects of Inhibition (Response Inhibition, Action Cancellation and Interference Control) and when analysed showed low or negative correlations with each other; this was not the case for the Working Memory or Mental Flexibility tasks. A similar two factor structure of Working Memory and Mental Flexibility but not Inhibition has also been confirmed by van der Sluis et al., (2007). However, St Clair-Thompson and Gathercole, (2006) identified Working Memory and Inhibition as separate factors, but not Mental Flexibility (Switching) in children aged eleven and twelve. Whilst there is disagreement regarding the exact composition of Executive Function in children aged six to twelve years, there is evidence to support that Executive Function at this age can be considered within a Unity and Diversity model.

3.3.1. Developmental Trajectory of Inhibition

There is growing evidence that the different components of Executive Function have differing developmental trajectories and that each reach maturity at different ages during childhood and young adulthood. Mental Flexibility has been found to develop into adolescence, whereas the development of Working Memory has been found to continue into adulthood (Huizinga et al., 2006). As Inhibition (Response Inhibition and Interference control) is the focus of this research, the developmental trajectory of this component of Executive Function is considered here. As mentioned previously, evidence of Response Inhibition has been found in children before the age of one (Diamond, 1985) and it has been found to continue to develop throughout childhood, reaching maturity at age eleven or twelve (Brocki & Bohlin, 2004; Levin et al., 1991). Interference control has also been found to improve throughout childhood (Bub et al., 2006) and reach maturity during the mid to late teenage years (Huizinga et al., 2006; Theodoraki et al., 2020). Hirst et al. (2019) found differing developmental trajectories for Interference Control depending on the type of distraction; unimodal (distraction in the same sensory system) or cross model (distraction in different sensory systems), in individuals aged six up to eighty four years. Unimodal interference followed an inverted U-shaped trajectory developmentally, suggesting peak performance in young adulthood. For multimodal distraction, children still performed poorly but the performance of older adults was not affected (Hirst et al., 2019).

Whilst a lot of the research does not specifically differentiate between the different types of Inhibition assessed (e.g. Huizinga et al., 2006; Klenberg et al., 2001), Brydges et al. (2013) simultaneously investigated the developmental trajectories of both Response Inhibition and Interference Control across children aged eight to eleven and in adults aged eighteen years. They used electroencephalography (EEG) to investigate brain activation patterns and how they change with age. They found that Response Inhibition and Interference Control follow distinct patterns of maturation. However, this research, like Hirst et al.'s (2019) did not include an older child group to be able to fully track this developmental progression. Collectively this evidence suggests that whilst Interference Control and Response Inhibition follow distinct developmental trajectories involving different brain regions, both are within the developing stage in children aged six to ten years, which is the age range of the children who participated in Study One and Two.

3.4. Assessments of Executive Function

Different methods are available for evaluating an individuals' ability to use Executive Function, for example questionnaires, standardised batteries and experimental tasks. However, there is currently no 'gold standard' assessment and the assessments available have widely reported limitations (Leonard & Hill, 2015; Sparrow & Hunter, 2012a). Issues with reliability (the extent to which the same results can be obtained on an assessment under the same conditions on different occasions) and validity (the extent to which an assessment measures what it intends) affects the ability to draw firm conclusions from the results of studies. Furthermore, reliability and validity can have a negative relationship on each other. For example, assessments of Executive Function that have higher ecological validity (better representing real life task performance) often sacrifice the highly structured nature of traditional standardised batteries or experimental tasks, therefore negatively impacting on the reliability of the results (Sparrow, 2012). Also, by developing a highly reliable and controlled experimental task to assess an isolated component of Executive Function, the validity of the result is reduced because components of Executive Function are used simultaneously within everyday life (Sparrow, 2012).

Related to this is the issue of ‘task impurity’ which occurs when an assessment relies on factors which are additional to the one of interest. This is common when attempting to isolate components of Executive Function from each other, as components are rarely used in isolation. However, this is also an important consideration when assessing components of Executive Function working together, as many assessments require additional performance domains such as motor or language skills. Commonly used assessments of Executive Function differ in their required response modality, with some requiring a motor response such as a fast button press and some a verbal response. It is often not considered in research how response modality can impact results, especially when used with a population of children with DCD. This can result in difficulty interpreting the extent to which a low score is truly representative of difficulties with Executive Function and not difficulties in these associated areas (such as the accuracy or speed of motor responses) (Sparrow, 2012). This will be discussed in more detail in chapter four. Interpretation of results across studies is also challenging due to the frequency with which tasks are adapted and the extent to which these adaptations change the task demands (Shilling et al., 2002). It has been reported that some of the adaptations to tasks for children have resulted in the measurement of an entirely different construct (e.g. Response Inhibition rather than Interference Control) (Esposito et al., 2013), which will be discussed in more detail below. The following section will provide an overview and critique of questionnaires, standardised batteries and experimental tasks used to measure Executive Function with a focus on Inhibition where appropriate. Examples of measures will be utilized for illustrative purposes, rather than providing an exhaustive list of measures. Details of some of the assessments will be provided in the next chapter.

3.4.1. Questionnaires

Parent/carer and teacher questionnaires can provide a measure of Executive Function within everyday life. Standardised questionnaires use rating scales to provide a numerical value reflecting the presence or frequency of every day behaviours associated with Executive Function. These scores can then be compared against age-based normative data to compare a person's performance with what is expected for their age. Different normative data should be provided for different raters (parent/carer, teacher, self) as research has shown that this can have a significant impact on results (Hartman et al., 2007; De Los Reyes & Kazdin, 2005). Questionnaires provide a good understanding of everyday performance, however, they have been found to have low correlations to performance-based measures (Toplak et al., 2013). Scores in questionnaires can be affected by how much support a child is receiving, which could mask difficulties that would be highlighted within a standardised battery or experimental tasks (Sparrow, 2012).

The Behaviour Rating Inventory of Executive Function 2nd Edition (BRIEF-2) (Gioia et al., 2015) and the original version, the Behaviour Rating Inventory of Executive Function (BRIEF; Gioia et al., 2000) are the most commonly used standardised parent/carer and teacher questionnaires to assess Executive Function (Toplak et al., 2013). The BRIEF-2 has US norms for children aged five years to eighteen years eleven months and provides separate normative data for different parents/carers and teacher raters and for males and females, as sex differences were found. The BRIEF-2 assesses everyday behaviour associated with Executive Function across nine domains (Inhibit, Self-Monitor, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Task-Monitor and Organization of Materials). Whilst several studies have reported significant correlations between performance-based measures of Executive Function components and the BRIEF (Anderson et al., 2002; Parrish et al., 2007; Toplak et al., 2009), these have not been found consistently. Toplak, West, and Stanovich, (2013) found that out of 182 reported correlations between the BRIEF and performance-based measures of Executive Function, only 35 were statistically significant with only weak correlations found (mean r =.15 and median r =.18). Whilst this research was conducted with the BRIEF, and results cannot necessarily be directly applied to the BREIF-2, these findings were similar for other questionnaire-based measures of Executive Function (Toplak et al. 2013). This suggests that whilst useful and valuable to provide insight into Executive Function skills within real life environments, parent/carer and teacher report measures of Executive Function, such as the BRIEF-2, likely assess different aspects of Executive Function compared to performance-based measures. It has been suggested that rating scales and performance tasks together provide a better understanding of Executive Function skills compared to either in isolation (Barkley & Murphy, 2010).

3.4.2. Standardised Batteries

A range of standardised batteries have been designed to examine the use of Executive Function within specific tasks and to compare results to what is expected for a person's age. These are administered under highly structured conditions. The tasks are often measured by the number of errors which are made or the time it takes to complete tasks. Two widely used batteries of Executive Function are the NIH Toolbox (Gershon et al., 2009) and Delis-Kaplan Executive Function System (Delis et al., 2001), which both have U.S. norms for children and adults. They both include tasks which assess individual components of Executive Function to provide information regarding the separate components (e.g. Inhibition). The NIH Toolbox, for example, includes three Executive Function tasks, one each to assess Inhibition (Flanker task), Mental Flexibility (Dimensional change card sort task), and Working Memory (list sorting work memory test). These tasks or versions of them have previously been used in research as experimental measures aimed to isolate the three components (Maurer & Roebers, 2019; Michel et al., 2018; Oberer et al., 2018; Stuhr et al., 2020). More recently, assessment batteries such as the Intelligence and Development Scales for Children and Adolescents 2nd Edition (IDS-2) (Grob & Hagmann-von Arx, 2017) provide a range of tasks designed to examine Executive Function components working together with particular tasks having larger demands from one component (e.g. Inhibition). At the time of writing the IDS-2 UK standardisation was currently underway. The IDS-2 Executive Function component has four tasks 1) Listing Words, 2) Divided Attention, 3) Animal Colours and 4) Drawing Routes. These tasks aim to assess Executive Function using the Unity and Diversity model. This is because the tasks do not aim to isolate components of Executive Function, but they do differ in the extent to which each task recruits the individual components. The Listing Words task, for example, requires children to list as many words as possible within a specified category, this has a larger Mental Flexibility demand compared to the Drawing Routes task, which requires children to plan and complete mazes without drawing over the same part of the route more than once. However, the Drawing Routes task does not intentionally exclude Mental Flexibility demands in the way that would be done in experimental tasks aiming to assess individual components or, as discussed previously, in other standardised assessments which also isolate individual components. The IDS-2 has been used in Study One and two of this research and will be discussed in more detail in chapter 6 (section 6.3.2.1.).

Standardised batteries have been criticised for lacking in ecological validity and not reflecting the task demands of real life (Toplak et al., 2013; Wallisch et al., 2018). Criticism is levied that explicit instructions reduce the novelty of the task and the requirement of problem solving skills, thus limiting the Executive Function demands (Sparrow, 2012). However, it has been argued that a child who has difficulties under these 'optimal' conditions would likely have difficulties in a more complex real world setting, and that those that do not show difficulties within this structured environment but do in the real world could benefit from more structured everyday life environments to minimise their difficulties (Toplak et al., 2013).

To address the criticism of low ecological validity, some standardised batteries have been designed to assess performance of everyday activities that require Executive Function. For example the DoEat assessment (Goffer et al., 2009) which requires the child to prepare a sandwich, a drink and to fill in a certificate of completion for themselves. However, performance in these types of assessments can be heavily influenced by difficulties in other domains such as motor skills. Furthermore, the rating of performance and structure of the task lacks the objectivity of more structured standardised tests.

3.4.3. Experimental Tasks

In research studies a range of highly controlled experimental tasks have been created to examine specific components of Executive Function whilst limiting the influence of other Executive Function components. These tasks do not have normative data to enable individual performance to be compared to age expectations but are typically used to compare group performance. These tasks meet similar criticism to the standardised performance tasks related to lack of ecological validity. A further criticism is the lack of standardised presentation when they are used across studies, which effects the comparability of results. Two of the most commonly used Inhibition tasks are the Go/Nogo task and the Stroop task.

The Go/Nogo task is a Response Inhibition task, mentioned previously, which requires participants to respond to a 'Go' cue and withhold a response to a 'Nogo' cue, for example, responding to green but not to red (Verbruggen & Logan, 2009). The 'Nogo' trials require participants to use Response Inhibition to override a prepotent response. In the Go/Nogo task, error rate and/or reaction time can be measured enabling the sensitivity of this task to be adapted depending on need. The Go/Nogo task has been shown to have good test-retest reliability and internal consistency for both response time and error rate measurements (Wostmann et al., 2013). This task is widely used with both children and adults (Verbruggen & Logan, 2009), however, there are a wide variety of Go/Nogo tasks used in research that vary in several ways such as the type of stimuli used (e.g. numbers, letters, geometric designs), the proportion of 'Go' to 'Nogo' cues as well as whether the task is computerized or not. This makes generalising evidence of reliability and validity from one Go/Nogo task to the next difficult, particularly as the tasks have not been compared to each other to show convergent validity (evidence that they measure the same construct) (Langenecker et al., 2007). This task has previously been used to assess Response Inhibition in children with DCD and will be discussed in chapter three.

The Stroop task, as mentioned previously, is commonly used to assess Interference Control. In this task the responder must say the colour of the ink a colour word is printed in (e.g. the word red printed in blue ink). This task meets the demands of an Interference Control task because it presents two domains 1) a colour word (e.g. red) and 2) the colour of the ink (e.g. blue) and only one of these domains is relevant to the task (the blue ink colour) the other is a distractor (the word red) (Laloi et al., 2017). This task was originally designed for adults and now several adaptations have been created for children, however, many of these have significantly altered the task demands (Esposito et al., 2013). A typical Stroop adaptation used with children is the ‘Day Night Stroop’ (Gerstadt et al., 1994). In this task children are required to respond with the word ‘night’ to a picture of a sun and ‘day’ to a picture of the moon. However, this adaptation only presents one domain (the picture) which is relevant to the response, there is no additional distracting information. Therefore, this popular adaptation of the Stroop task for children has resulted in the measurement of Response Inhibition rather than Interference Control (Esposito et al., 2013). This highlights the importance of assessing the validity of adaptations of assessments or new assessments of Executive Function to ensure they are accurately assessing what they claim.

There are several limitations to the available measures used to assess Executive Function and the absence of a ‘gold standard’ or widely renowned tool effects the certainty which can be placed in the results gained from an isolated measure. Questionnaires, standardised batteries and controlled experimental tasks appear to assess slightly different aspects of Executive Function. Therefore, to gain a comprehensive understanding of Executive Function for individuals and groups a variety of measures should be employed which include a mixture of questionnaires, standardised batteries, and experimental tasks.

3.5. Summary

This chapter has provided a justification for the use of the unity and diversity model of Executive Function for this research. There is evidence for the validity of the unity and diversity model in children aged six years up to adulthood. There is also evidence that Inhibition has emerged as a distinguishable component of Executive Function by age six. It is therefore appropriate to examine Inhibition in children aged six to ten years which is the focus of this research. Whilst Executive Function has a prolonged development period, there is also evidence that Inhibition is fully developed at the age of eleven years. Investigating the Inhibition skills of children with and without DCD and relationships between Inhibition and motor skills, in children aged six to ten years will enable a detailed understanding of Inhibition during its development. This chapter also highlighted that the neural networks associated with Executive Function are also associated with motor activity which suggests a neuro-anatomical justification for a relationship between Executive Function and motor skills. The following two chapters will provide literature reviews investigating the current understanding of the Inhibition skills of children with DCD (chapter four), and relationships between Inhibition and motor skills (chapter five).

4. Inhibition in Children with and without DCD: Literature Review for Study One

4.1. Introduction

Chapter one of this thesis provided an overview of DCD outlining the core characteristics of the condition as difficulties with motor skills that impact everyday life. Executive Function difficulties were also highlighted as both a potential underlying mechanism for the condition and a potential co-occurring difficulty (Blank et al., 2019). Chapter two described the Unity and Diversity model of Executive Function which conceptualises Executive Function as individual components that share underlying commonality (Miyake et al., 2000). This model has been found to be an appropriate representation of Executive Function from the age of six years to adulthood (Lemire-Rodger et al., 2019; Messer et al., 2018). Inhibition is a component of Executive Function which is responsible for overriding automatic but unhelpful responses and ignoring task irrelevant information (Nigg, 2000). Developmental evidence in typically developing populations suggests that Inhibition is separable from other components of Executive Function from the age of six (Messer et al., 2018) and in a developing stage until age eleven or twelve (Brocki & Bohlin, 2004; Levin et al., 1991). However, this has not been examined in children with DCD.

Effective Inhibition has been associated with better physical and mental health as well as better educational attainment (Moffit et al., 2011). Difficulties with Inhibition in children can lead to behaviours such as calling out in class and being easily distracted from work and leisure tasks. Therefore, Inhibition difficulties can have a direct impact on the learning of the individual as well as potentially disrupt wider class activity. Broad reviews of performance profiles of children with DCD have reported difficulties with Executive Function, including Inhibition (Blank et al., 2019; Wilson et al., 2017; Wilson et al., 2013). However, no review to date has considered the evidence for Inhibition difficulties in children with DCD in detail. This is important theoretically to gain a comprehensive profile of the performance of children with DCD to advance the understanding of the condition. This information also has practical relevance and could inform the assessments and support provided clinically for this population. The review presented in this chapter examines the details of research which has examined Inhibition in children with DCD. Chapter three (section 3.2.1) defined Inhibition as Response Inhibition which is the ability to override an automatic but unhelpful response, and Interference control which is the ability to ignore distracting information (Nigg, 2000). Different methods which are used to assess Executive Function were also outlined in chapter three (section 3.4.), these were questionnaires, standardised batteries and experimental tasks. This chapter outlines the literature examining Inhibition in children with DCD in the areas of Response Inhibition, Interference Control, standardised performance tasks, and questionnaires. It discusses the appropriateness of the methodologies used, the overall findings and considers the conclusions which can be drawn from the current work.

4.2. Search Protocol and Sample of Studies

Nineteen studies have been identified for inclusion in this review. These studies were identified through electronic data base searches (Web of Science, Cumulative Index to Nursing and Allied Health Literature, and PubMed) as well as reference list searches. Studies were included for review if they:

- Included a population of children aged between three and eighteen years
- Included a group of children with DCD, or who experience motor difficulties in line with those experienced by children with DCD
- Compared performance to a control group of children with typical motor skills, referred to here as a TD group
- Produced original data
- Included at least one measure to examine Inhibition specifically
- Were published in an English language journal

The large age range for inclusion was chosen due to the wide age ranges used in some of the previous literature. For example, Thornton et al. (2018) included children aged eight years to seventeen years, and Pratt et al., (2014) included children aged six to fourteen. Overall, there are only a small number of studies which have investigated differences in Inhibition skills between those with and without DCD. Inclusion of all these studies therefore provides the most comprehensive understanding of what is currently known regarding the Inhibition skills of those with and without DCD. However, it is important to note that due to the protracted development of Inhibition (see section 3.3.1), research with teenagers is not directly applicable to younger children. Therefore, the age range of the studies included will be considered throughout the discussion of the literature in this chapter.

Of the nineteen studies only fourteen confirmed DCD in line with DSM-4 or DSM-5 diagnostic criteria (APA, 2000; 2013). Tables 4.1. and 4.2. indicate whether or not this was confirmed for each of the studies (Alesi et al., 2019; Bernardi et al., 2016, 2018; Leonard et al., 2015; Mandich et al., 2002, 2003; Pratt et al., 2014; Querne et al., 2008; Rahimi-Golkhandan et al., 2016; Ruddock et al., 2015; Sartori, Valentini & Fonseca, 2020; Thornton et al., 2018; Koch et al., 2018; Houwen et al., 2017). However, Houwen et al. (2017) and Alesi et al. (2019) used a sample of children too young for a diagnosis of DCD (Blank, 2019). From these fourteen studies, two used the same sample of children (Bernardi et al., 2016; Leonard et al., 2015) and one followed up that same sample two years later (Bernardi et al., 2018). Four also included a third group (Bernardi et al., 2016, 2018; Leonard et al., 2015; Sartori, Valentini, & Fonseca, 2020). Sartori, Valentini and Fonseca, (2020) included a group of children whose motor skills fell between the 9th and 16th percentile on the MABC-2 Test but who were not assessed for the other DCD diagnostic criteria. They referred to this group as at risk for DCD ‘r-DCD’. Bernardi et al. (2016, 2018) and Leonard et al. (2015) included a group of children whose motor difficulties fell ≤ 16th percentile on the MABC-2 Test but, unlike their DCD group, did not have a formal diagnosis of DCD and were not assessed for the full DCD diagnostic criteria. They referred to this group as a ‘motor difficulties’ group.

Six studies compared one group of children with motor difficulties to a TD sample. Inclusion to the motor difficulties group was confirmed by a low score on a standardised test of motor performance but the full criteria outlined in the DSM-5 (APA, 2013) or International Guidelines for DCD was not confirmed (Koch et al., 2018; Michel et al., 2011, 2018; Piek et al., 2004; Rahimi-Golkhandan et al., 2014; Tsai, Pan et al., 2009). These six studies differ in the terminology they use to describe their sample, some still used the term DCD (Koch et al., 2018; Rahimi-Golkhandan et al., 2014; Tsai Pan et al., 2009), others used the term motor co-ordination impairment (Michel et al., 2018, 2011) or at risk for DCD (Piek et al., 2004). These studies have been included as they can provide useful information, however, caution is needed when considering the findings in relation to a confirmed clinical sample. These studies may have included children with medical conditions underlying their poor motor difficulties, children who have had a sudden decline in their motor skills or children for whom confirmed motor difficulties do not impact on everyday activities. All of the studies included either did not report if children with co-occurring conditions were included in the sample (Michel et al., 2018, 2011; Ruddock et al., 2015; Piek et al 2004; Mandich et al., 2003) or explicitly excluded children with co-occurring conditions (Sartori et al., 2019; Thornton et al., 2018; Bernardi et al., 2018, 2016; Leonard et al., 2015; Rahimi-Golkhandan et al., 2016, 2014; Pratt et al., 2014; Querne et al., 2008; Alesi et al., 2019; Koch et al., 2018; Tsai et al., 2009; Mandich et al., 2002; Houwen et al., 2017). All nineteen studies included a TD control group of children who scored within the typical range on a test of motor performance.

4.3. Response Inhibition

Response Inhibition has been investigated in children with DCD with a range of tasks. As mentioned in chapter three (section 3.2.1), Laloi et al. (2017) has defined a Response Inhibition task as a task which presents one dimension that has two competing responses. Using this definition the Response Inhibition tasks that have been used with children with DCD are: Go/Nogo tasks; the 'Verbal Inhibition Motor Inhibition (VIMI)' task (Henry et al., 2012); the Anti-Jump task; the Head Toes Knee Shoulders task; the Knock Tap Task and, the Hayling Test (Burgess & Shallice, 1997). Table 4.1. displays results of the thirteen studies which have examined Response Inhibition in children with and without DCD. The tasks are divided into those which required a verbal response and those which required a motor response, the importance of this will be discussed in more detail throughout the chapter. Temporal and spatial aspects of task performance have been measured in a variety of ways across studies; some have used error rate, some time and some both error and time. Temporal measures have included Reaction Time for a trial (RT), Movement Time for a trial (MT) and Completion Time for a block (CT). Querne et al. (2008) measures 'response time', however, like many studies that have measured RT Querne et al.'s (2008) response time measures the time taken from stimulus display to pressing the response key. Therefore, Querne et al.'s (2008) response time is referred to as RT throughout the chapter. Ruddock et al. (2015) is the only study to have a measure of MT for a trial, however a precise definition is not provided so it is unclear exactly what this measures and if the measurement includes RT or not. Furthermore, Ruddock et al.'s (2015) measure of inhibition is also the difference in MT between the control condition and the inhibition condition (MTdiff), rather than the total MT of the inhibition condition. Completion Time for a block includes the time from the first instruction to the end of the last movement of the last trial, therefore this time includes RT, MT and stimulus display time for each trial.

Table 4.1.

Summary of Main Findings from Studies on Response Inhibition in Children with and without DCD

				Task - Verbal Response			Task - Motor Response				
	Author	Age of Participants	DCD Assessed according to full diagnostic criteria	Hayling	VIMI Verbal	Go/Nogo	VIMI Motor	NEPSY Knock-Tap Task	Go/Nogo	Anti- Jump	Head Toes Knees Shoulders
1.	*Sartori, Valentini and Fonseca (2020)*	*8-9yrs*	Yes	****error*		****error*			****error*		
2.	*Michel et al. (2018)*	*4-6yrs*	No						****error*		**error*
3.	*Thornton et al. (2018)*	*8-17yrs*	Yes						*ns error* *ns RT*		
4.	*Bernardi et al. (2018)*	*7-11yrs*	Yes		*ns error*		****error*				
5.	*Bernardi et al. (2016)*	*7-11yrs*	Yes		****CT*		*ns CT*				
6.	*Leonard et al. (2015)*	*7-11yrs*	Yes		*ns error*		****error*				
7.	*Rahimi-Golkhandan et al. (2016)*	*7-12yrs*	Yes						**error[1]* **RT[1]*		
8.	*Rahimi-Golkhandan et al. (2014)*	*7-12yrs*	No						**error[1]* *ns RT*		
9.	*Ruddock et al. (2015)*	*6-12yrs*	Yes							**MTdiff* *ns error*	
10.	*Pratt et al. (2014)*	*6-14yrs*	Yes					*ns error*			
11.	*Querne et al. (2008)*	*8-13yrs*	Yes						** RT* *ns error*		
12.	*Piek et al. (2004)*	*6-15yrs*	No						*ns error*		
13.	*Mandich et al. (2003)*	*7-12yrs*	Yes						*** error* ***RT*		

Note:
1. ***p ≤ .001; ** p ≤ .01; * p ≤ .05; ns – no significant difference reported
2. Error – error rate; CT – Completion Time; MTdiff- Difference in Movement Time between control condition and Inhibition condition; RT – Reaction Time
3. [1] errors in emotional conditions only

The Go/NoGo task is the most frequently used measure of Response Inhibition with children with DCD. This task requires participants to respond to a 'Go' cue and withhold a response from a 'Nogo' cue. The presentation of the tasks can vary widely (e.g. stimuli used, ratio of Go to Nogo cues) although it is typically presented on a computer screen with the response method being a keyboard key or button box. Sartori, Valentini and Fonseca (2020), however, adapted this task for children with DCD to allow both motor and verbal responses to gain a better understanding of the role of motor demand on Executive Function performance for this group of children. In this study 397 eight and nine year old children from Brazil participated, This included 269 typically developing children (TD), 80 children with DCD (who scored ≤ 5th percentile on the MABC-2 Test and who met the full DCD diagnostic criteria), and 31 children at risk for DCD (r-DCD) (identified with a score between the 5th and 16th percentile on the MABC-2 Test). Children were presented with two forms of stimuli (auditory and visual) and two forms of response (motor - touching the display screen, and verbal - saying 'yes' when 'Go' items appear) on a smartphone. In all four conditions children were required to respond to sixty numbers from one to nine but withhold a response to the number six. The validity of this version of the Go/Nogo task was reported to be adequate for assessing Response Inhibition in children with DCD and typically developing children (Sartori, Valentini, Nobre, & Fonseca 2020). It was found to have good internal consistency (α =.82; ω = .82) and acceptable convergent validity evidenced by medium to small positive correlations (r = .12 - .39) between the sections of the task and the Brazilian version of the Hayling Test for children which is a measure of Response Inhibition requiring a verbal response (Siqueira et al., 2016).

Sartori, Valentini and Fonseca (2020) found that children aged eight to nine with DCD performed more poorly than age and sex matched TD children under all conditions (auditory – verbal; auditory – motor; visual – verbal; visual – motor). However, the r-DCD group (also aged eight and nine) did not differ significantly from the TD group on any of the conditions (comparisons between the DCD and r-DCD group were not reported). These findings highlight the difficulties of drawing conclusions regarding children with DCD from studies which did not meet the full DCD criteria. However, the cut off for inclusion in the DCD group for this study was lower (≤ 5th percentile) than for a clinical diagnosis of DCD (≤ 16th percentile) (Blank et al., 2019). Therefore it could be inferred that the lack of significant difference between the r-DCD and TD group could be explained by the more significant motor difficulties of the DCD group compared to the r-DCD group. This could suggest that the degree of motor difficulty may have a direct impact on Inhibition ability.

Other studies that have investigated the Go/Nogo paradigm with children with DCD have used only motor responses (button press, peddle press, touch screen) and have found varying results. Michel et al. (2018) used a Go/Nogo task from a German test battery (Hasselhorn et al., 2012) in which the child had to respond to or withhold a response (button press) to pictures of children with and without different coloured balloons and trousers. This task is reported to have ‘sufficient’ test retest reliability and construct validity (Hasselhorn et al., 2012). Michel et al. (2018) found that children aged four to six years with motor difficulties (identified as a score ≤ 10^{th} percentile on the Movement ABC-2 Test) made significantly more incorrect responses than a matched sample of TD children. However, unlike Michel et al. (2018), Piek et al. (2004) did not find a difference in error rate between children with and without poor motor difficulties using a Go/Nogo task, which required a button press. However, Piek et al. (2004) included children with a much larger age range (six to fifteen years), compared to Michel et al. (2018) so developmental differences may have influenced the results. Rahimi-Golkhandan et al. (2016, 2014) found that children aged seven to twelve years with motor difficulties only made significantly more errors in a Go/Nogo task, which required a button press to respond, when the stimulus was emotional (e.g. a happy face) and not when it was emotionless (e.g. a neutral face). This suggested that children with motor difficulties do not have difficulties with Response Inhibition unless coupled with an emotional component. However, information on the validity of the emotional Go/Nogo task was not provided, nor was information on the modified Go/Nogo task used in Piek et al.’s (2004) study. Piek et al. (2004) and Rahimi-Golkhandan et al. (2016, 2014) both used a cut off score of 80 on the McCarron Assessment of Neuromuscular Development (MAND) (McCarron, 1997) for inclusion in their motor difficulties group. Piek et al. (2004), Rahimi-Golkhanan et al. (2016, 2014), and Michel et al. (2018), did not meet the full DCD criteria, so caution is needed when interpreting these results in relation to children with DCD.

Like Rahimi-Golkhandan et al. (2016, 2014), Thornton et al. (2018), also used happy and sad faces as stimuli for a Go/Nogo task with a button press response. Thornton et al. (2018) investigated differences between children and adolescents aged eight to seventeen years in four groups: 1) those that met the full DCD diagnostic criteria alone 2) those that met the full Attention Deficit Hyperactivity Disorder (ADHD) criteria 3) those who met both the DCD and ADHD diagnostic criteria, 4) A TD control group. Thornton et al. (2018), unlike Rahimi-Golkhandan et al. (2016, 2014), found no difference in accuracy or RT between children with DCD or ADHD alone compared to TD children for either of the emotional stimuli. However, they found that children with a dual diagnosis of DCD and ADHD made significantly more errors than TD peers. Using functional magnetic resonance imaging Thornton et al. (2018) also found a significant difference in brain activation patterns during the Go/Nogo task for those with a dual diagnosis of DCD and ADHD compared to TD peers, but no significant difference was found for children with DCD and ADHD alone. A limitation of Thornton et al.'s (2018) research is that the DCD alone group included only nine individuals and all four groups included a large age range. This likely affected the extent to which a difference between the groups could be detected, as the low number included in the 'DCD' alone group may have not provided sufficient power, and the large age range allowed for developmental factors to potentially mask group differences.

In contrast to these results, Mandich et al. (2003), like Sartori, Valentini and Fonseca (2020), found that children aged seven to twelve years who met the full DCD diagnostic criteria responded more frequently to Nogo cues (red circles rather than green circles) than age and gender matched TD peers. Mandich et al. (2003) also found that children with DCD responded more slowly than TD peers. However, the Go/Nogo task used in Mandich et al.'s (2003) study included additional elements not presented in traditional Go/Nogo tasks. For example, the target appeared on different parts of the screen with spatial cues regarding its potential location. This could have changed the demands of the task and had an effect on the results. Querne et al. (2008), unlike Sartori, Valentini and Fonseca (2020) or Mandich et al. (2003) did not find a difference in error rate between children aged eight to thirteen years who met the full DCD diagnostic criteria and TD peers on a Go/Nogo task. However, Querne et al. (2008) also examined RT and found, like Mandich et al. (2003), that children with DCD responded significantly slower than TD peers. However, the Go/Nogo task used in Querne's (2008) study required children to press a response key to any sequentially presented letter (Go trial) except 'x' (Nogo trial). This is a potential limitation of this study as children with DCD are known to have higher rates of language and reading impairments (Kirby et al., 2014) which were not controlled for and could have impacted the results.

Sartori, Valentini and Fonseca (2020) present the only study that considered the effect of response modality on the results of the Go/Nogo task when used with children with DCD. They found that children aged eight and nine years with DCD had a higher error rate than those with typical development in conditions which required both a motor and a verbal response. The effect of response modality on Inhibition performance in a population of children with motor difficulties is an important consideration. However, whilst Table 4.1. separates tasks into those which required a motor response and those which did not, Bernardi et al. (2016) and Leonard et al. (2015) are the only other authors to have considered the potential effects of response modality (verbal vs motor) on Response Inhibition in a group of children with DCD and a group of typically developing children. It is difficult to compare group differences in motor and verbal responses in the other literature as varying demands of the different tasks used potentially affect the results obtained. Bernardi et al. (2016) and Leonard et al. (2015) adapted the ‘Verbal Inhibition Motor Inhibition’ (VIMI) task, an experimental task designed by Henry et al. (2012) to assess Response Inhibition in children with Developmental Language Disorder aged six to fourteen years. This task required children to copy what the tester said or say a paired opposite word in the verbal condition, and to copy what the tester did or produce a paired opposite action in the motor condition.

Unlike Sartori, Valentini and Fonseca (2020), Bernardi et al. (2016) and Leonard et al. (2015) found that results differed across the response modalities. Children with DCD aged seven to eleven years made significantly more errors than their TD peers when a motor response was required but not when a verbal response was required (Leonard et al., 2015). Further differences were found when investigating completion time, as children with DCD were found to have longer completion times for each verbal block (20 trials) but not each motor block compared to TD peers (Bernardi et al., 2016). Bernardi et al. (2016) argued that this result was because the verbal task was within the capabilities of the children with DCD if they took their time but that the motor task by, comparison, was too hard so children disengaged and did not take the time they might have required to improve their accuracy. Whilst it is important to consider both accuracy and time when investigating differences between the groups, the use of completion time for each block lacks the precision needed to draw firm conclusions from these results. The measurement of completion times was calculated from the mean of each block of 20 trials across all eight blocks (four congruent, four incongruent). Therefore, because this measure is collapsed across many trials this may have enabled factors other than the ability to inhibit a prepotent response to effect results, such as distractibility and inattention. Children with DCD are reported to have higher rates of inattention and hyperactivity compared to TD peers (Crane et al., 2017).

Interactions between accuracy and time within Response Inhibition tasks have not been widely researched in children with DCD. The few studies that have considered both accuracy and time have inconsistent results. Rahimi-Golkhandan (2016, 2014) found no differences between children with DCD and typically developing children on accuracy or time for non-emotional stimuli, but did find differences for accuracy (Rahimi-Golkhandan et al., 2014, 2016) and RT (Rahimi-Golkhandan et al., 2016) for emotional stimuli. Thornton et al. (2018) used happy and sad faces in a Go/Nogo task and found no difference between children and adolescents with DCD and typically developing children on accuracy or RT. Querne et al. (2008) in a Go/Nogo task found that children with DCD and TD peers had similar error rates but that children with DCD had significantly slower response times. Mandich et al. (2003) also had differing results using a Go/Nogo task finding that children with DCD had both higher error rates and longer response times. However, as outlined above all of these Go/Nogo tasks had fundamental differences in their task demands which effects the ability to directly compare results across studies.

Ruddock et al. (2015) used a different Response Inhibition task with children aged six to twelve years old. This task required children to respond in the opposite direction to where the central cue moved (e.g. if the cue moved right the child was required to move left) using a touchscreen. Ruddock et al. (2015) found that children with DCD and typically developing children had similar error rates on this task but that children with DCD had a larger increase in their movement time between the control condition and Inhibition condition (MTdiff). This indicated that they required longer to complete their movement when an Inhibition demand was added to the task. However, when Ruddock et al. (2015) considered the results by age, they found that children with DCD aged six to nine years had longer total MTdiff than typically developing children, but found no significant difference in MTdiff between children with DCD and TD peers age ten to twelve. This highlights the importance of considering age when reviewing research in this area as developmental differences potentially impact results. As Ruddock et al. (2015) found no difference in error rate between children with DCD and TD peers at any age this suggests that younger children with DCD, may have performed more slowly to ensure greater accuracy. Speed-accuracy trade-offs have been widely reported within tasks that require a rapid response (Bogacz et al., 2010; Dutilh et al., 2011; Uemura et al., 2013). However, many studies which have used these types of tasks to investigate Response Inhibition in children with DCD have only recorded either accuracy or time for each task. To create a full profile of performance and enable a comprehensive comparison between the groups it is important to measure both accuracy and time and to consider the relationship between the two.

4.3.1. Response Inhibition Summary

Thirteen studies have investigated the Response Inhibition skills of children with and without DCD. Overall, the results suggest that children with DCD have difficulties with Response Inhibition. However, results are inconsistent across studies limiting the certainty of this conclusion. Research has differed in the measurement of temporal and spatial aspects of performance as well as in the response modalities required by the tasks which limits the extent to which results can be compared. Few studies have considered the impact of response modality (verbal vs motor) on a group of children with DCD and those which have, have found varying results. Furthermore, some of the studies have included large age ranges in their participants with small sample sizes. Therefore, developmental differences between participants could have affected the results.

4.4. Interference Control

Interference Control has been examined in children with DCD using a range of tasks. Using Laloi et al.'s (2017) definition of an Interference Control task (one which presents two conflicting dimensions with only one relevant to the task) the Interference Control tasks which have been used with children with DCD are: Stroop, Simon and Flanker tasks. Table 4.2. displays results of the seven studies which have examined Interference Control in children with and without DCD. Similarly, to Response Inhibition, these tasks have been divided into those which required a verbal response and those which required a motor response. However, no research has considered the impact of response modality using Interference

Control tasks with a motor and verbal response and caution is needed when considering the effect of response modality across research which has used different tasks and different participant groups. Whilst Pratt et al. (2014) only considered error rate, all other studies have considered a measure of both error rate and time. Michel et al. (2011) reported a response time, and Alesi et al. (2019) reported an execution time, however these appear procedurally the same as RT used by the other studies so are referred to as RT here.

Table 4.2.

Summary of Main Findings on Interference Control in Children with and without DCD

				Task - Verbal Response	**Task - Motor Response**		
	Authors	Age of Participants	DCD Assessed according to full diagnostic criteria	Stroop	Number Stroop	Simon task	Flanker
1.	*Alesi et al. (2019)*	*3-6yrs*	Yes	****error ns RT*			
2.	*Michel et al. (2018)*	*4-6yrs*	No				****error ns RT*
3.	*Koch et al. (2018)[1]*	*8-12yrs*	Yes[1]		** RT ns error*		
4.	*Pratt et al. (2014)*	*6-14yrs*	Yes	***error*			
5.	*Michel et al., (2011)*	*5-7yrs*	No	** RT ns error*			
6.	*Tsai, Pan et al. (2009)*	*9-10yrs*	No			**error ***RT*	
7.	*Mandich et al. (2002)*	*7-12yrs*	Yes			*** error ***RT ns Simon effect*	

Note: 1. [1] some of the children did not clearly meet criterion B
2. ***p ≤ .001; ** p ≤ .01; * p ≤ .05; ns – no significant difference reported
3. Error – error rate; RT– Reaction Time; Simon Effect – different in RT between congruent and incongruent condition

Versions of the Stroop task have been used by Alesi et al. (2019), Koch et al. (2018), Pratt et al. (2014), and Michel et al. (2011). Alesi et al. (2019) used an Animal Stroop task with children aged three to six years, who despite satisfying the full DCD diagnostic criteria were referred to as ‘at risk of DCD’ due to their young age. In this Animal Stroop task children were required to correctly identify a hybrid of two animals by ignoring the head and responding only to the body of the animal. Alesi et al. (2019) found that children at risk of DCD had higher error rates compared to age and gender matched TD peers but that the groups did not differ according to RT. Pratt et al. (2014) found similar results using a traditional Stroop task in which children were required to respond to colour words by saying the colour ink the words were printed in rather than reading the words. Pratt et al. (2014) found that children aged six to fourteen years who met the full DCD diagnostic criteria made more errors than TD peers, RT was not recorded.

Whilst Alesi et al. (2019) and Pratt et al. (2014) found similar results, Michel et al.'s (2011) results contrast with these. Michel et al. (2011) used a Fruit Stroop task with children aged five and seven years old with and without motor difficulties. The Fruit Stroop task required children to correctly identify fruit colours despite their presenting colour (e.g. to say 'yellow' to a picture of a purple banana). Michel et al. (2011) found no difference in error rate between children with and without motor difficulties but did find that children with poorer motor skills had longer RTs than those without. Koch et al.'s (2018) results are also in line with those found by Michel et al. (2011) despite the age difference of their samples. Koch et al. (2018) used a Number Stroop task with children with and without motor difficulties aged between eight and twelve. The Number Stroop required children to respond to the number of times a number appeared on the screen rather than reading the number itself (e.g. the correct answer to '4444' is four, but the correct answer to '4' is one). Interference Control was required when the number on the screen and the number of times it was presented was incongruent. Unlike traditional Stroop tasks which require a verbal response, this task required a button press. Koch et al. (2018) found no difference in error rate between children with and without motor difficulties but did find that those with poorer motor skills had longer RT. However, no interaction was found between group and condition for RT so this slower RT could be because children with poorer motor skills react more slowly than those with better motor skills rather than an indication of poorer Interference Control skills.

A fundamental difference between Michel et al.'s (2011) and Koch et al.'s (2018) research compared to Alesi et al. (2019) and Pratt et al.'s (2014) research is that Michel et al. (2011) and Koch et al.'s (2018) participants did not meet the full DCD diagnostic criteria. They instead separated children into groups based on manual dexterity scores below and above the 10^{th} percentile (Michel et al., 2011) or total scores lower than the 10^{th} percentile on the MABC-2 Test (Koch et al., 2018). The

Stroop task has also attracted criticism due to the wide range of adaptations available and evidence that individuals who are sensitive to the interference in one Stroop task are not necessarily sensitive to interference in a different version (Shilling et al., 2002).

A Simon task is a measure of Interference Control which requires participants to respond quickly and accurately to stimuli which are laterally incongruent to the response location (e.g. a stimulus presented on the right and response key on the left). Tsai, Pan et al. (2009) and Mandich et al. (2002) have used this task and found differing results. Tsai, Pan, et al. (2009) used four different versions of a Simon task with children aged nine to ten years who they identified as having DCD (however, the criterion they used for DCD was a total score ≤ 5^{th} percentile together with a Balance score ≤ 10^{th} percentile on the MABC-2 Test), and a group of TD children. Tsai, Pan et al. (2009) found that the children with DCD had a higher error rate in a Simon task which required a response via a foot pedal but not in Simon tasks that required a response with a key press. However, this higher error rate was only found in the version of the Simon task which required attention to a variety of pre cues which provided correct, neutral or misleading information regarding the stimulus location. Tsai, Pan et al. (2009) did however find that children in the DCD group had significantly slower RT compared to the TD group in all four versions of the Simon tasks (response using a foot or key press in conditions with and without cues).

Mandich et al. (2002) used a Simon task with a group of children aged seven to twelve years who met the full DCD diagnostic criteria and TD peers. Children were required to respond to green circles by pressing a key on their right, and red circles by pressing a key on their left regardless of which side of the screen the target appeared. Interference Control was needed when the stimulus and response location were on opposite sides. Mandich et al. (2002) found that children with DCD made more errors than typically developing children and that they had slower RT. However, unlike Tsai, Pan et al. (2009) Mandich et al. (2003) did not use RT as their dependent variable but instead used the size of the Simon effect (the extent to which RT increases between congruent and incongruent trials). They found no difference in the size of the Simon effect between groups. These results indicate that whilst children with DCD did react more slowly overall, they did not require a longer RT to inhibit responses, although their responses were less accurate compared to TD peers.

Michel et al. (2018) used a Flanker task to examine Interference Control in children aged four to six years with and without motor difficulties. Children were required to press a right or left button according to the direction a middle fish was swimming regardless of the direction of the flanking fish. During the incongruent condition the Flanker fish faced the opposite way to the target fish and this required Interference Control. Michel et al.'s (2018) research included a test of motor skills and then a one year follow up. Children were divided into three groups based on their performance on the MABC-2 Test: the first group included children whose motor skills were poor at time point one and also at one year follow up, the second group included children who had poor motor skills at time point one but by time point two their motor skills fell in the typical range and a third group who had typical motor skills at both time points. Michel et al. (2018) found that children whose motor difficulties persisted had poorer accuracy on the incongruent condition of the Flanker task compared to children in the other two groups. Michel et al. (2018) also found that an ANOVA revealed a main effect of group membership on Flanker RT but that post hoc tests did not differentiate between the three groups. Mean scores, however, showed that children whose motor difficulties persisted had slower RTs than the other two groups.

Whilst the Flanker and Simon tasks required a motor response and three of the four Stroop tasks required a verbal response, no study has compared the effect of response modality on Interference Control performance in children with DCD. Pratt et al. (2014) did consider the effect of response modality on Inhibition, without specifying the type of Inhibition and found that children with DCD performed worse than TD peers on tasks with a verbal response but no differently on tasks with a motor response. However, the tasks that Pratt et al. (2014) used measured different types of Inhibition; the verbal task was a Stroop task which is a measure of Interference Control and the motor task was The NEPSY Knock Tap task (Korkman et al., 1998) which is a measure of Response Inhibition. This would have affected the ability of these tasks to reflect the influence of motor load, as different types of Inhibition were assessed within each task it is likely the results reflect this rather than differences in response modality. It is important for research to examine the effect of response modality without altering the fundamental Interference Control demand of the task.

A larger proportion of the research investigating Interference Control has measured both accuracy and time, in comparison to the Response Inhibition literature. However, time has not always been measured in the same way, effecting the comparability of results across studies. Within research that used Simon tasks for example, Tsai, Pan et al. (2009) found differences between children with DCD and typically developing children in RT, whereas Mandich et al. (2002) used the size of the Simon effect (the extent to which RT increased between the congruent and incongruent condition) as their measure. Mandich et al. (2002) reported that there was a significant difference between groups in RT, however, as this was not the focus of their research, they did not use statistical tests to directly investigate the difference between RT for congruent and incongruent conditions separately. Fundamental differences in task design which used the same paradigm also makes the comparison of accuracy and time scores across studies challenging. For example, Alesi et al. (2019) used a version of the Stroop task yet found differing results to Michel et al. (2011) and Koch et al.'s (2018) research for accuracy and time. Despite all three studies using versions of the Stroop task, the design of each version varied greatly. Therefore, it is important for research to continue to examine both accuracy and time within Interference Control tasks.

4.4.1. Interference Control Summary

Seven studies have investigated the Interference Control skills of children with and without DCD. Overall, the results suggest that children with DCD have difficulties with Interference Control. However, similar inconsistencies that occurred when considering studies that investigated Response Inhibition in children with DCD and typically developing children occurred when examining Interference Control. These include differences in the tasks used, how these are measured, and the large age range of participants included in the research. This affects the confidence which can be placed in the overall conclusion that children with DCD have difficulties with Interference Control as developmental differences and differences in measurement may have influenced results. Furthermore, no study has considered the impact of response modality on the results of Interference control tasks in children with DCD or typically developing children.

4.5. Performance Tasks from Standardised Batteries

Chapter 3 (Section 3.4.2.) provided examples of standardised batteries used to assess Executive Function. Several studies have investigated Executive Function skills in children with DCD using tasks from standardised test batteries (e.g. Michel et al., 2018; Pratt et al., 2014). However, these tasks have been used as experimental measures aimed to isolate Inhibition from other Executive Function components rather than assessing Inhibition working alongside other components. Few studies have used an entire standardised battery of Executive Function rather than individual tasks, and none have done so to examine Executive Function components (including Inhibition) working together. Therefore, no studies were found that used a standardised battery of Executive Function that met the search criteria for this review.

4.6. Questionnaires

Parent/carer and teacher questionnaires can also be used to examine Inhibition within the context of the Unity and Diversity model of Executive Function. As mentioned in Chapter Three (section 3.4.1), the Behaviour Rating Inventory of Executive Function 2nd Edition (BRIEF-2) and Pre-School Edition (BRIEF-P) questionnaires provide a separate score for Inhibition specifically (Diversity) as well as an Overall Executive Function Score (Unity) called the Global Executive Function Composite which is the sum of all the individual component scores including Inhibition. Houwen et al.'s (2017) study is the only one to have used a questionnaire to assess Inhibition in children with and without motor difficulties. Houwen et al. (2017) used the BRIEF-P questionnaire in a group of children with and without motor difficulties aged three to five years and found that they did not differ in parent/carer reported Inhibition skills. However, in children this young there is evidence that Executive Function works at only the unity level and separate components have not yet emerged (Hughes et al., 2010; Wiebe et al., 2008). Houwen et al. (2017) did find differences in Executive Function skills between those with and without motor difficulties on the working memory and Plan/Organize subscales, but results regarding overall Executive Function on the Global Executive Composite score were not reported for either group. Whilst Houwen et al. (2017) applied the full DCD diagnostic criteria, due to the young age DCD could not be confirmed and they were referred to as 'at risk' for DCD. No research has considered teacher perspectives of Inhibition. To gain a comprehensive understanding of the Inhibition skills of children with and without DCD within the Unity and Diversity model, it is important that both parent/carer and teachers' perceptions are considered (Messer et al., 2018).

4.7. Summary of Findings

Overall, children with DCD appear to have difficulties with Inhibition compared to TD peers. Difficulties with Inhibition have been found across experimental measures of Response Inhibition and Interference Control. No research has yet examined Inhibition skills in everyday life in children who meet the full DCD diagnostic criteria. However, in a parent/carer questionnaire, children with motor difficulties aged three to five years old were not found to significantly differ in their Inhibition skills compared to TD peers. Inhibition has also not been examined using a standardised battery of tasks aimed at examining Executive Function components working together. It is important to acknowledge that there were many limitations in the research reviewed and findings are not consistent across the literature. It is also important to highlight the large age range included in the review and the potential for developmental differences to have influenced results across studies. Another limitation is that some of the literature that has been used to inform the conclusion that children with DCD have difficulties with Inhibition did not examine the full DCD diagnostic criteria in participants. Few studies have investigated the effect of response modality (verbal vs. motor) on the Inhibition performance of children with DCD compared to TD peers and of those which have, there are differing results. Studies have often failed to explicitly state which aspect of Inhibition was under investigation, and at times that has led to inappropriate interpretation of results. Many studies have also failed to record both an accuracy and time score for the tasks used, and when time has been considered this has been done inconsistently across studies. Parent/carer perspectives have been considered in only one study and this was with a group of children who were too young to receive a formal DCD diagnosis in line with international guidelines for DCD (Blank et al., 2019).

No study has yet sought to comprehensively investigate Inhibition using a combination of: experimental tasks designed to assess both Response Inhibition and Interference Control including both verbal and motor responses, a standardised battery aimed to investigate Inhibition in the context of other Executive Functions and parent/carer and teacher questionnaires aimed to gain an understanding of Inhibition in everyday life. Therefore, the aim of Study One was to:

- Examine the Inhibition skills of children with and without DCD using a broad range of measures: Response Inhibition and Interference control tasks, a standardised battery and parent/carer and teacher questionnaires.

4.8. Predictions for Study One

4.8.1. Predictions for Response Inhibition Tasks

1. Children with DCD will have higher error rates compared to typically developing children for the Response Inhibition task which requires a motor response.
2. Children with DCD will have longer RT compared to typically developing children for the Response Inhibition task which requires a motor response.
3. Children with DCD will have longer MT compared to typically developing children for the Response Inhibition task which requires a motor response.
4. Children with DCD will not differ from typically developing children in their error rate for the Response Inhibition task which requires a verbal response.
5. Children with DCD will not differ from typically developing children in their RT for the Response Inhibition task which requires a verbal response.

Due to the mixed findings of previous research the current predictions are based on the skill automatisation deficit hypothesis of DCD outlined in chapter two (section 2.4.1.1.). If children with DCD have deficits with skill automatisation this may affect their ability to respond quickly and accurately when a motor response is required but not when a verbal response is required. .

4.8.2. Predictions for Interference Control Tasks

6. Children with DCD will have higher error rates compared to typically developing children in Motor Interference Control.
7. Children with DCD will have longer RT compared to typically developing children in Motor Interference Control.
8. Children with DCD will not differ from typically developing children in their verbal Interference Control error rate.

9. Children with DCD will not differ from typically developing children in their verbal Interference Control Completion Time.

Due to the mixed findings of previous research, predictions for Interference Control performance are also informed by the skill automatisation deficit hypothesis of DCD.

4.8.3. Predictions for Standardised Performance Tasks

10. It is predicted that children with DCD will have poorer scores on a standardised test of Executive Function which aims to assess Executive Function components working together compared to typically developing children.

This prediction is informed by the Unity and Diversity model of Executive Function outlined in chapter two. This model posits that Executive Functions have diversity evidenced by individually distinct components (such as Inhibition, Working Memory and Mental Flexibility) as well as Unity, as these components have underlying shared commonality (Miyake et al., 2000). It is predicted above (section 4.8.1 and 4.8.2) that children with DCD will have difficulties with Inhibition, which has also been found in previous literature, difficulties with other components of Executive Function have also previously been found (Wilson et al., 2017, 2013). Therefore, using the Unity and Diversity model it is predicted that children with DCD will have difficulties on standardised tasks of Executive Function that assess components working together.

4.8.4. Predictions for Questionnaires

11. It is predicted that children with DCD will have poorer parent/carer reported Inhibition than typically developing children.
12. It is predicted that children with DCD will have poorer teacher reported Inhibition skills than typically developing children

Houwen et al. (2017) are the only authors to have considered the parent/carer reported Inhibition skills of children with DCD. Houwen et al. (2017) did not find that children with motor difficulties had poorer parent/carer reported Inhibition skills, however, as mentioned previously Houwen et al. (2017) used a sample of children too young for a DCD diagnosis and arguably too young for Inhibition to have emerged as a separate component of Executive Function (Hughes et al., 2010; Wiebe et al., 2008). No study has yet examined the teacher reported Inhibition skills of children with DCD. Predictions eleven and twelve therefore are based on anecdotal evidence from clinical practice that children with DCD have difficulties with Inhibition skills in everyday life.

5. Relationships between Inhibition and Motor Skills: Literature Review for Study Two

5.1. Introduction

To gain a thorough understanding of Inhibition difficulties in DCD it is important to ascertain the nature of the relationship with the difficulties with motor skills. This could further the understanding of DCD and potentially have implications for interventions used in clinical practice (van der Fels et al., 2015). Some of the research investigating group differences between those with and without motor difficulties have found Inhibition difficulties in children whose motor skills fall ≤ 5th percentile but not in children whose motor skills fall between the 9th and 16th percentile in a standardised test of motor performance (Sartori, Valentini, Fonseca, 2020). Furthermore, Molitor et al. (2015) found that despite children with poor motor skills having difficulties with Inhibition, a subsample of children with poor overall motor skills but comparatively good fine motor skills did not experience Inhibition difficulties. This suggests that there could be a relationship between the extent and/or profile of motor skill difficulty and the presence of Inhibition difficulties. As outlined in chapter two, whilst children with DCD must have motor skills which, on a standardised test fall ≤16th percentile (Blank et al., 2019), the severity and profile of their motor difficulties are heterogeneous. Results from research investigating group differences in Inhibition skills between children with DCD and typically developing children are varied. This suggests that the profile of the children's motor difficulties could be important.

Contemporary developmental frameworks recognise the cascading effects and interaction of different domains in skill acquisition (e.g. Adolph & Hoch, 2019). Motor and Executive Function skills have been considered to have a dynamic interaction with each other. As children develop motor skills they increase their ability to interact with and learn from their environment (Adolph & Hoch, 2019; Von Hofsten, 2009), this advances their Executive Function skills which continues to have a reciprocal effect on their interactions with the environment (Campos et al., 2000; von Hofsten, 2007). Response Inhibition, for example, is required to learn and complete complex motor tasks which require the suppression of prepotent responses, such as dynamic sports (e.g. football) that require quick adaptations to movements based on a changing environment (van der Fels et al., 2019; Pennequin et al., 2010). Diamond, (2000) emphasised the importance of

Executive Function especially when learning novel motor tasks, with declining Executive Function involvement as the motor task becomes more automated. Therefore, as outlined in the skill automatisation deficit hypothesis of DCD, in chapter two (section 2.4.1.1.), a person with poor motor skills may take longer to automatise motor tasks. Therefore, it is possible that they are relying on Executive Function skills to complete the task more than peers with better motor skills. However, Maurer and Roebers, (2019) found significant relationships between fine motor and Executive Function skills within both ‘easy’ and ‘difficult’ fine motor tasks in children aged five and six. This suggests that this relationship is potentially more intricate than a novel or complex motor task presenting an Executive Function challenge. Alternatively, it is possible that even the ‘easy’ fine motor task for children aged five to six was difficult enough to present an Executive Function challenge.

Neuroimaging research, highlighted in chapter two (section 2.4.1.3.), also provides evidence of a relationship between motor and Executive Function skills. Crucial structures for motor and Executive Function skills such as the cerebellum, dorsolateral prefrontal cortex and connecting structures, including the basal ganglia, have been found to co-activate in both motor and Executive Function tasks (Abe & Hanakawa, 2009; Diamond, 2000; Hanakawa, 2011). This suggests that the output of this neural circuit influences both motor and Executive Function control. Furthermore, there is evidence that motor skills and Executive Function follow similar developmental trajectories both developing rapidly in pre-school years (Piek et al., 2012) and continuing to develop over a protracted period (Diamond, 2000).

Relationships between motor and Executive Function skills have been examined in children with DCD, typically developing (TD) children, and in samples of children with a range of motor skills. In a systematic review of research involving typically developing children, van der Fels et al. (2015) found ‘strong evidence’ against a relationship between gross motor skills and Executive Function, as well as insufficient evidence of a relationship between fine motor skills and Executive Function. This review, however, included only five studies investigating relationships between Executive Function and motor skills and failed to provide information on the measures used. Furthermore, it included only papers published prior to 2013 and therefore did not consider more recent research which has reported significant correlations between Executive Function and motor skills

(Roebers et al., 2014; Schmidt et al., 2017). Roebers et al. (2014), for example examined relationships between Executive Function and fine motor skills in 169 typically developing five and six year olds and found significant positive correlations indicating that better Executive Function skills were associated with better fine motor skills. Roebers et al. (2014), examined Executive Function as a general construct, however, one of the three tasks used was a measure of Interference Control, the Fruit Stroop task. Whilst van der Fels et al. (2015) did not find evidence of Global-Global relationships between motor and Executive Function skills in their systematic review, they emphasised the importance of considering relationships across different domains of motor skills and Executive Function. No research to date has reviewed the literature regarding relationships between motor skills and Inhibition specifically. Therefore this chapter considers studies that have examined relationships between Inhibition and different domains of motor skills in children with a range of motor skills.

Motor skills have been examined in many ways across the literature, with variation in the structure, content and labelling of assessment components. The review presented in this chapter considers four general categories to provide coherence across the range of assessments used: (1) overall motor skills, (2) gross motor skills, (3) ball skills, and (4) fine motor/drawing skills. The most commonly used assessment is the MABC-2 Test (Henderson et al., 2007) (or its predecessor the MABC, Henderson & Sugden, 1992) which measure a broad range of skills, categorised into Manual Dexterity, Aiming & Catching and Balance, as well as providing an overall score for motor performance. The McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1997) has also been used as a measure of overall motor performance (Piek et al., 2004). This assessment includes fine motor tasks such as manipulating beads and screwing nuts onto bolts, and gross motor tasks such as balancing on one leg, and long jump. The Test of Gross Motor Development 2nd Edition (TGMD-2; Ulrich, 2000) has also been used in this field of work. This categorises gross motor skills into locomotion and object control. Locomotion is assessed using tasks such as running, galloping, hopping, leaping, jumping, and sliding, and object control assesses aspects of ball skills such as catching and kicking. The K*ö*rperkoordinationstest F*ü*r Kinder (KTK; Kiphard & Schilling, 2007) has also been used to assess gross motor skills (Maurer & Roebers, 2019; van der Fels et al., 2019) and similar to the TGMD-2, includes tasks such as jumping sideways, moving sideways and balancing. The

Peabody Developmental Motor Scale 2nd Edition (PDMS-2) (Folio,& Fewell, 2000) has also been used to assess gross motor skills (Simpson et al., 2017), including tasks such as throwing and catching, jumping, balancing on one leg and walking along a line. The PDMS-2 has also been used to assess fine motor skills and includes tasks such as construction, folding and cutting (Simpson et al., 2017). Other tests used to assess fine motor skills include the Purdue Pegboard Test which requires children to insert pegs into a peg board under time constraints (Stuhr et al., 2020). Other studies have also used tasks to specifically assess drawing skills (Riggs et al., 2013; Simpson et al., 2017).

The following review is organised according to the four categories of motor skills mentioned above. The review considers research which has examined relationships between these motor categories and Inhibition skills in children with DCD, TD children and across children with a range of motor skills.

5.2. Search Protocol and Sample of Studies

Eighteen studies have been identified for inclusion in this review. Table 5.1. displays findings from the reviewed research according to the previously mentioned motor domains. These studies were identified through electronic data base searches (Web of Science, Cumulative Index to Nursing and Allied Health Literature and PubMed) as well as reference list searches. Studies were included for review if they:

- Included a population of children aged between three and eighteen years
- Examined relationships between at least one measure of Inhibition and one measure of Motor skills
- Produced original data
- Were published in an English language journal

Studies were excluded if they examined relationships in a group of children with physical, neurological, or sensory difficulties (e.g. cerebral palsy, sight loss).

The large age range for inclusion was chosen due to the wide age ranges used in some of the previous literature. For example, Piek et al. (2004) included children aged six to fifteen years and Pratt et al. (2014) included children aged six to fourteen. Given that overall there are only a small number of studies available in this area, inclusion of those with a larger age range provides the most comprehensive understanding of what is currently known about relationships between Inhibition and motor skills in children. However, it is important to note that due to the protracted development of Inhibition (see section 3.3.1), research in teenagers cannot be directly applied to younger children and visa-versa. Therefore, the age range of the studies included will be considered throughout the discussion of the literature in this chapter. From the eighteen studies included: four investigated relationships separately in TD children and those with DCD (Michel et al., 2018, 2011; Alesi et al., 2019; Pratt et al., 2014), eleven did not report the motor skills of children included (Stein et al., 2017; Livesey et al., 2006; Cook et al., 2019; Aadland et al., 2017; Maurer & Roebers 2019; Simpson et al., 2019; Ludyda et al., 2019; Riggs et al., 2013; Stuhr et al., 2020; Oberer et al., 2018; van der Fels et al., 2019), and three included between 7.6% - 32% of their sample as children with motor difficulties (Rigoli et al., 2012; Houwen et al., 2017; Piek et al., 2004).

Table 5.1

A Summary of Relationships between Inhibition Measures and Domains of Motor Skill in Children

	Authors	Sample Size	Age (yrs)	Sample (DCD/ TD/ Mix)	Inhibition Type	Overall Motor Skills	Gross Motor Skills	Ball Skills	Fine Motor/ Drawing Skills
1.	Michel et al. (2018)	*48*	*4-6*	*DCD*	*IC*	*.43**			
				DCD	*RI*	*ns*			
		48		*TD*	*IC*	*ns*			
				TD	*RI*	*.35**			
2.	Rigoli et al. (2012)	*93*	*12-16*	*Mix*[1]	*RI*	*.28****	*ns*	*ns*	*.23**
3.	Stein et al. (2017)	*102*	*5-6*	*Mix*[2]	*RI*	*.35***	*.33***	*.34**	*.34***
4.	Livesey et al. (2006)	*36*	*5-6*	*Mix*[2]	*RI*	*.45***[6]	*ns*	*.40***[6]	*.59***
5.	Houwen et al. (2017)	*153*	*3-5*	*Mix*[3]	*Q*	*ns*	*ns*	*-.17***	*ns*
6.	Alesi et al. (2019)	*18*	*3-6*	*DCD*	*IC*	*ns*	*ns*	*ns*	*ns*
		18		*TD*	*IC*	*ns*	*ns*	*ns*	*ns*
7.	Pratt et al. (2014)	*26*	*6-14*	*DCD*	*IC*	*ns*	*ns*	*ns*	*ns*
		26		*DCD*	*RI*	*ns*	*ns*	*ns*	*ns*
		24		*TD*	*IC*	*ns*	*ns*	*ns*	*ns*
		24		*TD*	*RI*	*ns*	*ns*	*ns*	*ns*
8.	Piek et al. (2004)	*238*	*6-15*	*Mix*[4]	*RI*	*ns*			
9.	Cook et al. (2019)	*129*	*3-6*	*Mix*[2]	*RI*		*.57***	*.44***	
10.	Oberer et al. (2018)	*134*	*5-7*	*TD*[5]	*IC*		*32***[7]		*.35****[7]
11.	Aadland et al. (2017)	*129*	*10*	*Mix*[2]	*IC*		*.16**[7]	*-.19**	
12.	Maurer and Roebers (2019)	*124*	*5-6*	*Mix*[2]	*IC*		*.20**[7]		*.19**[7]
13.	Simpson et al. (2019)	*100*	*3-4*	*Mix*[2]	*RI*		*.63****	*.63****	*.75****[7]
14.	Ludyga et al. (2019)	*89*	*10-12*	*Mix*[2]	*IC*		*ns*	*.37***[7]	
15.	van der Fels et al. (2019)	*732*	*8-10*	*Mix*[2]	*IC*		*.10***[6]	*.10***[6]	
					RI		*.25***	*.25***	
16.	Stuhr et al. (2020)	*41*	*5-6*	*Mix*[2]	*IC*		*ns*		*.37**
					RI		*ns*		*ns*
17.	Riggs et al. (2013)	*50*	*3-5*	*Mix*[2]	*RI*				*.64****
18.	Michel et al. (2011)	*47*	*5-7*	*DCD*	*IC*				*ns*
		47		*TD*	*IC*				*ns*

Note: *p ≤ .05; ** p ≤ .01; ***p ≤.001
ns – no statistically significant relationship reported; IC – Interference Control; RI – Response Inhibition, Q – Questionnaire
DCD – used to encompass: 'DCD'; 'at risk for DCD' & 'motor difficulties' groups
[1]7.6% of sample had motor difficulties ≤16th percentile MABC-2
[2]Motor profiles of sample not provided
[3]32% of sample had motor difficulties ≤16th percentile MABC-2
[4]11.8% of sample had motor difficulties (≤ 80 Neurodevelopmental Index of MAND)
[5]Sample described as 'TD', however no inclusion/ exclusion criteria or motor profiles were provided
[6]Relationships no longer significant when controlling for covariates such as age
[7] Relationships differed across measures used, highest correlation reported in table

5.3. Overall Motor Skills

Eight studies have examined relationships between Inhibition and overall motor skills (measured by a total score on a battery of motor tasks) in various samples of children, and report varying results. Whilst four studies found a significant relationship indicating that poorer motor skills are associated with poorer Inhibition skills, four of the studies did not find a significant relationship. The ages of the children included in studies where significant relationships were found between Inhibition and overall motor skills (four to sixteen years) were similar to the studies where significant relationships were not found (three to fifteen years).

Livesey et al. (2006) found a relationship between overall motor skills and a day/night Stroop task but not a stop signal task. However, when controlling for age no relationship between Inhibition and overall motor skills remained significant (Livesey et al., 2006). In a mixed sample of children aged 12–16 years, including those with and without motor difficulties, Rigoli et al. (2012) found a relationship between Response Inhibition and overall motor skills. However, in a group of children which included those with and without motor difficulties, Piek et al. (2004) did not find a significant relationship between Response Inhibition and overall motor skills. However, the children in Piek et al.'s (2004) study also covered a broader age range (six to fifteen years) compared to Rigoli et al. (2012) and this may have influenced their results.

Michel et al. (2018) examined relationships between Inhibition and overall motor skills in three groups of children aged four to six years: those with poor motor skills which persisted for one year, those with poor motor skills that improved to typical performance after one year and those with consistently typical motor skills over a one year period. They found differing relationships between overall motor performance and Inhibition within each group. Children with persistently poor motor skills were found to have a significant relationship between overall motor performance and accuracy on the Flanker Interference Control task. However, children with consistently typical motor performance were found to only have relationships between overall motor skills and the accuracy of two Response Inhibition measures. No significant relationships were found between overall motor performance and Inhibition in children whose motor skills improved from poor to typical performance within the year. This suggests that the level of motor skills could influence the relationship between Inhibition and overall motor skills.

However, Alesi et al. (2019), did not find a relationship between overall motor performance and Interference Control in children with or without motor difficulties aged three to six years. Unlike Michel et al. (2018), Alesi et al.'s (2019) results suggest that relationships do not differ depending on the level of motor skills. However, it should be noted that Alesi et al. (2019) only included 18 children in each group which could have reduced the chance of detecting a relationship. Pratt et al. (2014), with a sample of children with and without DCD aged six to fourteen years, also did not find a relationship between overall motor skills and measures of Response Inhibition or Interference Control when these were examined in children with DCD and typically developing children separately. However, Pratt et al.'s (2014) research included a large age range in a sample of 24 typically developing children and 26 children with DCD. The substantial differences in Inhibition skills throughout this age range could have influenced the chance to detect a relationship between motor and Inhibition skills.

Piek et al. (2004), similar to Pratt et al. (2014) included a sample of children with a wide age range (six years to fifteen years) and did not find a relationship between error rate on a Go/Nogo Response Inhibition task and overall motor performance measured by the MAND (McCarron, 1997) in a sample of children with mixed motor skills. In contrast, Stein et al. (2017), in children whose motor skills were not stated, and who had a narrower age range (five to seven years) compared to Piek et al. (2004) did find a relationship between Response Inhibition and overall motor skills. Rigoli et al. (2012), in a sample of older children aged 12–16 years with a range of motor skills also found that poor motor skills were associated with slower completion time on the NEPSY-11 Response Inhibition task (Korkman et al., 2007).Houwen et al.'s (2017) study was the only one to consider relationships between overall motor skills and Inhibition using a parent/carer questionnaire. They did not find a relationship between Inhibition and overall motor skills or any of the motor domains in children aged three to five years with a range of motor skills. However, low correlations between Executive Function performance measures and questionnaires suggest that these different assessment tools measure different types of Inhibition (Ten Eycke et al., 2016; Toplak et al., 2009). This effects the ability to compare Houwen et al.'s (2017) results directly to other studies which have used performance tasks. It is important that future research includes both performance tasks and questionnaires to provide a full understanding of relationships between Inhibition and overall motor performance.

5.4. Gross Motor Skills

Fourteen studies have examined relationships between gross motor skills and Inhibition in varied samples of children. Gross motor skills are measured differently across the literature, although the most commonly used assessment was the MABC-2 (or MABC) Test balance component score (Alesi et al., 2019; Houwen et al., 2017; Pratt et al., 2014; Rigoli et al., 2012; Stein et al., 2017; Livesey et al. 2006)). Motor skills have also been assessed using TGMD-2 (Cook et al., 2018) which provides separate scores for locomotion and object control (see section 5.1.) The MOBAK-5 has also been used (Ludyga et al., 2019) and provides separate scores for locomotion which is assessed using a balancing task, rolling, rope skipping and running, and object control which is assessed using throwing, catching, bouncing and dribbling tasks. The results of the locomotion results of these studies (Cook et al., 2018 & Ludyga et al., 2019) are considered here, and the object control results are considered in section 5.5. Two studies (Maurer & Roebers, 2019; van der Fels et al., 2019) have used tasks from the KTK as a measure of gross motor skills which included jumping sideways, moving sideways (Maurer & Roebers, 2019; van der Fels et al., 2019), and balancing (Van der Fels et al., 2019). Van der Fels et al. (2019) also used an assessment of ball skills from the Bruninks-Oseretsky Test of Motor Proficiency 2nd Edition (BOT-2) (Bruininks, 2005) and created a gross motor factor which included the three KTK tasks and the BOT-2 ball skills score. Therefore, in some studies ball skills cannot be separated from other gross motor skills and the results will be considered in this section and section 5.2. In Table 5.1. the results from the correlational analysis are presented under both gross motor skills and ball skills. This is also true for Simpson et al. (2019) who used a measure of gross motor skills (the PDMS-2) which included ball skills, jumping, balancing on one leg and walking along a line. The study by Oberer et al., (2018) has also been included in this review. Whilst this study aimed to assess relationships between Inhibition and physical fitness, it included individual correlations between a measure of Inhibition and the jumping sideways task from the KTK, long jump which is included as a gross motor task in the MAND, and running which is included as a gross motor measure in the TGMD-2 and MOBAK. The complexities of these differences in measurement will be considered further below.

The research was evenly split between those studies which found a significant relationship between gross motor skills and Inhibition (seven) and those which did not (seven). The age of participants in studies which did find a significant relationship ranged from three to ten years, and the age of participants in studies which did not find a significant relationship ranged from three to sixteen years. Three studies included children aged eleven years or older (Rigoli et al., 2012, Pratt et al 2014, and Ludyga et al 2019) and none of these studies found a significant relationship between gross motor skills and Inhibition. Most of the research that did not find significant relationships used the MABC or MABC-2 Test balance component as a measure of gross motor skills (Alesi et al., 2019; Houwen et al., 2017; Pratt et al., 2014; Rigoli et al., 2012). However, Stein et al. (2017), in a sample of children whose motor skills were not reported, was the one study which did find a significant relationship using this measure. Whilst Maurer and Roebers (2019) did find a relationship between Inhibition and gross motor skills, in a sample of children whose motor skills were not reported, this relationship was only found when using measures of jumping sideways and not when using tasks from the MABC-2 balance component. Therefore, the differences found across the studies could relate to the different measurement of gross motor skills used.

Van der Fels et al. (2019), in a sample of children whose motor skills were not reported, used a gross motor factor in their analysis of typically developing children aged eight to ten years. As described above, this factor reduced four gross motor variables (jumping sideways quickly, moving sideways quickly, balancing, and ball skills) into one score which explained most of the shared variance. Using this gross motor factor van der Fels et al. (2019) found relationships between gross motor skills and Response Inhibition and Interference Control. However, the relationships between gross motor skills and Interference Control did not remain significant when age, sex and socioeconomic status were accounted for in a multivariate multilevel regression analysis. Cook et al. (2019) found a relationship between gross motor skills and Response Inhibition in a sample of children aged three to six years whose motor skills were not reported, using the locomotion component of the TGMD-2. As well as including broader measures of gross motor skills compared to the MABC-2 Test, this assessment differs from the MABC-2 Test as the pattern or quality of performance on each task was scored according to qualitative criteria rather than scoring performance on measures of speed and accuracy. Both Aadland et al. (2017) (in a sample of children aged 10 whose motor skills were not reported) and Oberer et al. (2018) (in a sample of ‘typically developing children’ aged five to seven whose motor skills were not reported) also found relationships between gross motor skills and Inhibition using measures that included running. The tasks used by Oberer et al., (2018) were similar to those used by Cook et al. (2019) (running and jumping) however, as discussed above Oberer et al. (2018) classified these measures as physical fitness rather than gross motor skills. Whilst Aadland et al. (2017) classified their shuttle run as a measure of gross motor skills, they also used another running task as a measure of physical fitness and found relationships between this task and Inhibition. This suggests that Aadland et al. (2017); Cook et al. (2019) and Oberer et al.'s (2018) research could more accurately represent a relationship between physical fitness and Inhibition, rather than gross motor skills and Inhibition. A relationship between Inhibition and physical fitness has been widely reported (Ishihara et al., 2018; Khan & Hillman, 2014).

From the fourteen studies which have investigated relationships between Inhibition and gross motor skills, eight studies have used a measure of Interference Control, eight have used a measure of Response Inhibition and one used a questionnaire. Results are inconsistent when the same area of Inhibition has been examined across different studies. Aadland et al. (2017), for example, found a relationship between an Interference control measure and gross motor skills in a sample of children aged ten whose level of motor skills was not reported. In contrast, Ludyga et al. (2019), in a similar sample of children aged ten to twelve years whose level of motor skills was not reported, did not find a relationship between Interference Control and gross motor skills. Furthermore, Simpson et al. (2019) found a relationship between a Response Inhibition measure and a gross motor measure, whereas Livesey et al. (2006) in a similar sample of children whose motor skills were not reported did not.

5.5. Ball Skills

Eleven studies have investigated relationships between ball skills and Inhibition in varied samples of children and have found varying results. Eight studies found a significant relationship between ball skill and Inhibition (in samples of children ranging from three to twelve years), and three studies did not find a significant relationship (in samples of children aged three to sixteen years). However two studies, which found a significant relationship (Simpson et al., 2017; van der Fels et al., 2019) have used a measure which incorporates ball skills and gross motor skills (e.g. jumping and balancing) (as discussed in section 5.4.). Furthermore, results are less conclusive when the different areas of Inhibition are examined separately. From the eleven studies, seven used a measure of Response Inhibition, five used a measure of Interference Control and one used a questionnaire. Studies which have considered Response Inhibition include five studies which found a relationship (Cook et al., 2019; Livesey et al., 2006; Simpson et al., 2019; van der Fels et al., 2019; Stein et al., 2017) (however the relationship found by Livesey et al. (2006) was no longer significant when age was accounted for), and two which did not find a significant relationship (Pratt et al., 2014; Rigoli et al., 2013). Studies which have considered Interference Control include three which have found a relationship to ball skills (Aadland et al., 2017; Ludyga et al., 2019; van der Fels et al., 2019) (however the relationship found by van der Fels et al. (2019) was no longer significant when age, sex and socioeconomic status was accounted for), and two which did not find a significant relationship (Alesi et al., 2019; Pratt et al., 2014). One study used a parent/carer questionnaire to investigate the relationships between everyday Inhibition skills and ball skills, in a sample of children with mixed motor skills, and did find a relationship (Houwen et al., 2017). Overall, these results tentatively suggest a relationship between Inhibition and ball skills, however, relationships are not consistent across the different tasks used or different samples of children.

The differences found across studies could be related to the different measurements of ball skills used. Cook et al. (2019), Ludyga et al. (2019) and van der Fels et al. (2019) were the only studies to include measures of both upper and lower body ball skills and all found relationships between ball skills and Inhibition. The other eight studies only used measures of upper body ball skills. However, Aadland et al. (2017), Houwen et al. (2017), Simpson et al. (2019) and Stein et al. (2017) also found relationships between the different areas of Inhibition and ball skills. Therefore, differences in the results across studies cannot exclusively be explained by the differences in the measures of ball skills used. Other reasons for differences in the results found across studies could be the varying age range of participants used and/or differences in task demands when studies were examining the same area of Inhibition.

5.6. Fine Motor/ Drawing Skills

The most compelling evidence for a relationship between motor and Inhibition skills is between Inhibition and the domain of fine motor skills, as the largest proportion (eight out of twelve studies) found a significant relationship. Fine motor skills encompass a range of different skills including one handed (unimanual), and two handed (bimanual) skills. Tasks such as drawing (sometimes referred to as 'visuomotor' skills), can also be included under the term fine motor skills. Some assessments (e.g. the IDS-2 Psychomotor component) classify drawing tasks as 'visuomotor' skills and consider these separately from other fine motor skills. Other assessments (e.g. the MABC-2 Test) include drawing tasks in the assessment of fine motor skills. Drawing and fine motor skills are considered together in this section. Twelve studies have considered relationships between Inhibition and fine motor skills in various samples of children. Eight studies found a significant relationship in samples of children who range in age from three to sixteen years, and four did not find a significant relationship in samples of children who range in age from three to fourteen years (Alesi et al., 2019; Houwen et al., 2017; Michel et al., 2011; Riggs et al., 2013). Seven studies have used a measure of Response Inhibition with four finding a significant relationship (Livesey et al., 2006; Riggs et al., 2013; Rigoli et al., 2012; Simpson et al., 2019) and three not finding a significant relationship (Pratt et al., 2014; Stein et al., 2017; Stuhr et al., 2020). Seven studies have used a measure of Interference Control with three finding a significant relationship (Maurer & Roebers, 2019; Oberer et al., 2018 and Stuhr et al., 2020) and three not finding a significant relationship (Alesi et al., 2019; Michel et al., 2011; Pratt et al., 2014). One study considered relationships between Inhibition in everyday life and fine motor skills, in a sample of children with mixed motor skills aged between three to five years, and did not find a significant relationship (Houwen et al., 2017).

Relationships between Inhibition and fine motor skills have been found in children aged three (Simpson et al., 2019) to sixteen (Rigoli et al., 2012) years. From the eight studies that found at least one significant relationship between a measure of Inhibition and fine motor skills, six did not report the overall levels of motor skills of the children included (Livesey et al., 2006; Maurer & Roebers, 2019; Oberer et al., 2018; Riggs et al., 2013; Simpson et al., 2019; Stein et al., 2017) and Rigoli et al. (2012) reported that in a sample of ninety three adolescents only five scored ≤ 5^{th} percentile on the MABC-2 Test total score. Rigoli et al. (2012), Simpson et al. (2019), and Maurer and Roebers (2019) further reported that children were excluded if they had behavioural or developmental difficulties. In contrast Houwen et al. (2017) investigated relationships between parent/carer reported Inhibition skills and fine motor skills in a sample of children aged three to five years, nearly a third of whom had motor skills that were ≤16th percentile on the MABC-2 Test and did not find a significant relationship. This could suggest that children with and without motor difficulties have differing relationships between Inhibition and motor skills which effected Houwen et al.'s (2017) ability to detect a relationship when combining the groups. However, Pratt et al. (2014) and Alesi et al. (2019) did not find a significant relationship between fine motor skills and Interference Control (Alesi et al., 2019; Pratt et al., 2014) or Response Inhibition (Pratt et al., 2014) when these were examined in children with and without motor difficulties separately. Similarly, Michel et al. (2011) also did not find a relationship between fine motor skills and Interference Control when relationships were examined separately in children with and without fine motor difficulties. This potentially provides evidence that those with and without motor difficulties have similar relationships between fine motor skills and Inhibition. However, as mentioned previously, methodological issues such as Pratt et al.'s (2014) large age range (six to fourteen years) and small sample size, and Michel et al.'s, (2011) motor difficulties group being identified by poor motor skills alone, effects the ability to directly compare these studies to each other and the wider literature.

5.7. Summary of Findings

Understanding relationships between Inhibition and motor skills can provide insight into whether Inhibition difficulties observed in children with DCD are directly related to their motor difficulties or if they simply co-occur. Furthermore, developing a greater knowledge of relationships between Inhibition and motor skills may help to inform understanding of the individual differences in Inhibition ability seen in children with DCD. This could lead to a better understanding of the individual profiles of children with DCD as well as a greater theoretical understanding of the condition. A thorough knowledge of relationships between motor and Inhibition skills could also influence further research investigating whether improvements in one domain (e.g. Inhibition) could also lead to improvements in the other domain (e.g. motor skills), this could have an impact on the interventions used with children with DCD and what areas of improvement are to be expected.

Whilst several studies have investigated relationships between Inhibition and motor skills in children, the results have been inconclusive. Houwen et al. (2017)

and Geuze et al. (2015) emphasised the importance of including children with a range of motor skills in the same sample, including those with and without motor difficulties when investigating relationships between Executive Function and motor skills. Four of the seventeen studies investigated relationships between Inhibition and motor skills in children with DCD (or 'motor difficulties') and typically developing children separately (Alesi et al., 2019; Michel et al., 2018, 2011; Pratt et al., 2014). This limited the range of scores available and therefore the ability of the studies to detect relationships. Three studies did include a group of children with mixed motor skills, with percentages of children with motor difficulties ranging from 7.6% - 32%. However, the majority of studies investigated relationships in a group of children whose level of motor skills were not reported (Aadland et al., 2017; Cook et al., 2019; Livesey et al., 2006; Ludyga et al., 2019; Maurer & Roebers, 2019; Riggs et al., 2013; Simpson et al., 2019; Stein et al., 2017; Stuhr et al., 2020). In Table 5.1. these studies have been labelled as a 'mix' sample because no criteria were stated which would exclude children with poor motor skills.

As mentioned in the previous chapter, difficulties occur when reviewing studies which have considered Inhibition. These include: the wide range of tasks that have been used and lack of standardised procedures when the same task has been used; the wide age range used, the lack of investigation regarding the effect of response modality (verbal vs. motor), and the disparity in how studies recorded performance (speed or accuracy). Furthermore, studies have failed to investigate relationships between the full Inhibition construct and motor skills. Pratt et al. (2014) has highlighted the investigation of Response Inhibition and Interference Control separately as a priority for future research. Therefore, the aim of Study Two was to:

- Examine the relationships between Inhibition skills (Response Inhibition, Interference Control, parent/carer and teacher reported Inhibition) and Motor Skill (Gross Motor Skill, Ball Skill, Fine Motor Skill and Drawing Skill) in children with and without DCD.

Study Two is exploratory in nature and no predictions have been made. This is due to the challenges of drawing conclusions from previous literature regarding the expected nature of relationships between the different types and measures of Inhibition and the different domains of motor skill.

6. Methods

6.1. Introduction

This chapter provides a detailed description of the methods used to meet the aims of Study One and Two outlined in chapters four (section 4.8.) and five (section 5.8.). The aim of Study One was to examine the Inhibition skills of children with and without DCD. The aim of Study Two was to examine the relationships between Inhibition skills (Response Inhibition, Interference Control, parent/carer and teacher reported Inhibition) and Motor Skills (Gross Motor skills, Ball skills, Fine Motor and Drawing skills) in children with and without DCD. Due to the limited research in this area, Study Two was exploratory in nature. Study One and Two were undertaken with the same participants, measures, and procedures, however, different data analysis techniques have been used to meet the aim of each study.

Procedures for selecting participants for this research are outlined below. This includes details of how the DSM-5 diagnostic criteria for DCD were applied and how the International Guidelines for DCD (Blank et al., 2019) were adhered to. The rationale and description of measures used to examine motor and Executive Function skills (with a specific focus on Inhibition) are provided. Measures are described under the 'Selection Criteria Measures' if they were used to evidence inclusion criteria, 'Supplementary Measures' if they provide background analysis or are used in additional analysis included in the appendix, and 'Standardised Measures and Experimental Tasks' if they were used within the main analysis of Study One and/or Two. Motor skills were assessed in relation to aspects of quality and/or speed of movement in the areas of:

- Gross motor skills, including aiming and catching.
- Fine motor skills, including drawing skills.

Executive Function was assessed at three levels, which simultaneously increased in ecological validity whilst decreasing in the degree of experimental control. These measures were:

- Experimental tasks specifically designed to isolate Inhibition from other components of Executive Function
- A standardised battery of Executive Function aimed to assess components of Executive Function working collaboratively

- Standardised parent/carer and teacher questionnaires.

The procedures for both Study One and Two are then described, and the different data analysis techniques are outlined and justified.

6.2. Participants

An a-priori power analysis found that a sample size of 24 children with DCD and 24 controls was the minimum needed to find a 1-tailed difference with a large effect size between each group (.8) with a power of 85%. A total of 50 children participated in each of the two studies, 25 children with Developmental Coordination Disorder (DCD) aged between six to ten years and 25 typically developing (TD) controls matched on age (+/- six months) and sex. The minimum age of six years was chosen as the youngest that could manage the experimental measures for this research. In Study One the main focus was on group comparisons between the DCD and TD group. In Study Two the groups were combined for some analyses, together they represent children with a range of motor skills. The age range was chosen because it is the age at which there is evidence that Inhibition emerges as a separate component of Executive Function (Messer et al., 2018), but is still developing (Leon-Carrion et al., 2004). Due to the protracted development of Executive Function, it was important to match the groups on age. It was also important to control for sex as some measures of Executive Function have been found to have sex differences (Gioia et al., 2015; Grissom & De Los Reyes, 2019). This is an important consideration as DCD is diagnosed more frequently in males compared to females with ratios varying from 2:1 to 7:1 (Blank et al., 2012). All of the children completed all of the domains of the IDS-2 assessment which included: Intelligence, Executive Function, Psychomotor, Social-Emotional and Scholastic skills (including maths, language, reading and spelling) (see Appendix A for further details of the full assessment). However, standard scores were not available at the time of writing, so results from all domains are not reported. Only data from the IDS-2 Executive Function and Psychomotor components are reported in this thesis.

6.2.1. Recruitment

6.2.1.1. DCD Group. Recruitment of children with DCD was from the Oxford Brookes University DCD database (UREC number: 080369). Families are invited onto this database via various routes. For Study One and Two this included inviting parents/carers through the following:

1) A 'learn to ride a bike' course and Saturday activity club for children with motor difficulties in Oxford.
2) A Special Educational Needs and Disabilities Coordinator at a mainstream school in London.
3) Word of mouth recommendations from parents/carers who had previously participated in the study.

6.2.1.1.1. DCD Diagnostic Assessment. DCD was confirmed through a full diagnostic assessment in line with the International Guidelines for DCD and DSM-5 criteria (APA, 2014) (see chapter 2 Table 2.1. and 2.2.). All children were assessed by the same tester and had the first testing session for the studies within three months of a diagnostic assessment. Details of how the DSM-5 diagnostic criteria were operationalised are shown below. The rationale for and descriptions of the specific measures used is provided later in this chapter (6.2.2.).

A) The presence of a significant motor difficulty was confirmed by a total test score at or below the 16th percentile on a standardised test of motor skills, the Movement Assessment Battery for Children 2nd Edition (MABC-2) Test (Henderson et al., 2007). Children whose total score fell on the 16th percentile on the MABC-2 Test were also required to obtain a score ≤ 5th percentile on at least one component tested (manual dexterity, aiming and catching or balance). Of the 25 children with DCD, 19 had scores at or below the 5th percentile, four had scores on the 9^{th,} and two had scores on the 16th.
B) Motor difficulties were confirmed to have a significant impact on daily life as indicated by a poor score on parent/carer questionnaires, the MABC-2 Checklist (Henderson et al., 2007) and the Developmental Coordination Disorder Questionnaire (DCDQ; Wilson et al., 2009).
C) A parent/carer telephone interview confirmed onset of symptoms in early/middle childhood.

D) A parent/carer telephone interview confirmed the absence of neurological or intellectual impairment or medical condition, which could better explain the motor difficulties, as well as adequate prior learning opportunities. Whilst every child completed the full IDS-2, which included a measure of IQ, standard scores were not available at the time of writing. Therefore, the British Picture Vocabulary Scale 3rd edition (BPVS-3) (Dunn et al., 2009) which is a measure of receptive language was used to provide a quick measure of verbal ability. The BPVS-3 correlates highly with verbal IQ (Glenn & Cunningham, 2005) and is commonly used in DCD research to provide evidence for criterion D. Scores on the British Picture Vocabulary Scale 3rd edition (BPVS-3) (Dunn et al., 2009) were within two standard deviations from the mean ≥ 70.

6.2.1.1.2. Inclusion Criteria for DCD Group. Table 6.1. summarises the inclusion criteria for the DCD group to ensure the children met the diagnostic criteria for a DCD diagnosis. Co-occurring conditions were not part of the exclusion criteria, due to the high prevalence within clinical samples of children with DCD (Kirby et al., 2014). It was therefore reasoned that excluding co-occurring conditions would lessen the external validity of the results of the research. In the DCD group eight children were reported by parents/carers to have co-occurring conditions; six children had Autism Spectrum Condition (ASC), one had Attention Deficit Hyperactivity Disorder (ADHD) and one had both ASC and ADHD. Parents/carers were also requested to complete the Strengths and Difficulties Questionnaire (Goodman & Goodman, 2009) and demographic information sheet to provide supplementary information, however, this information was not used to apply the inclusion/exclusion criteria.

Table 6.1.

Inclusion Criteria for the DCD group

Skill Domain	Measurement
Motor Skills	MABC-2 Test standard score ≤ 7 (16th percentile) MABC-2 Checklist score above the 95th percentile (within the significant difficulties range) DCDQ score within the ‘indication of DCD range’
Cognitive Skills	BVPS-3 standard score ≥ 70 Absence of intellectual disorder, visual impairment or neurological condition (e.g. cerebral palsy) according to parent/carer report

6.2.1.2. TD Control Group. TD children were recruited through opportunity sampling. Children were recruited through the tester’s personal networks, schools, and recommendation from previous participants. Children recruited into the TD group completed the MABC-2 Test and BPVS-3 to assess their eligibility for inclusion into the study.

6.2.1.2.1. Inclusion Criteria for TD Group. Table 6.2 outlines the Inclusion Criteria for the TD group. A child was included in the TD group if they had a total standard score of > 7 on the MABC-2 Test (above the 16th percentile) (Henderson et al., 2007) to ensure typical motor performance. They also required a standard score of ≥ 70 on the BPVS (Dunn et al., 2009). Children were excluded from the TD group if they were reported to have a clinical diagnosis of intellectual disorder, visual impairment, DCD, ADHD, ASC, or any neurological condition by a parent/carer, as that would exclude them from being classified as ‘TD’. Parents/carers were also requested to complete the Strengths and Difficulties Questionnaire (Goodman & Goodman, 2009) and demographic information sheet to provide supplementary information, however, this information was not used to apply the inclusion/exclusion criteria.

Table 6.2.

Inclusion Criteria for TD Group

Skill Domain	Measurement
Motor Skills	MABC-2 Test standard score > 7 (16th percentile)
Language Skills	BVPS-3 standard score ≥ 70
Cognitive Skills	Absence of any diagnosed condition (e.g. ADHD, ASC, Cerebral Palsy, Intellectual disability) according to parent/carer report

6.2.1.2.2. Excluded Participants from TD Group. Eleven children originally assessed for the TD group were excluded: ten children were found to have scores at or below the 16th percentile on the MABC-2 Test. One child was excluded due to a standard score of below 70 on the BPVS-3. None of these children met the full diagnostic criteria for inclusion into the DCD group.

6.2.2. Selection Criteria Measures

6.2.2.1. Movement Assessment Battery for Children 2nd Edition (MABC-2) Test (Henderson et al., 2007). The MABC-2 Test is a standardised test of motor performance with UK norms for children aged three to sixteen years. It is an established measure frequently used in clinical and research settings and is listed in the International Guidelines for DCD. The test takes approximately 25 minutes to administer and consists of eight test items which assess the areas of manual dexterity, aiming and catching and balance. Raw scores are converted into Standard Scores (SS) which have a mean of 10 and a standard deviation of 3, higher scores indicate better performance on all tasks. The test items are divided into three age bands (three-six; seven-ten, and eleven-sixteen years); similar tasks, which increase in difficulty, are used across the age bands. The first two age bands were used in both Study One and Two.

Table 6.3.

Movement Assessment Battery for Children 2nd Edition Test Components (MD, A&C and Bal) for Age Band One and Two

Component	**Tasks**		
Manual Dexterity	MD 1	MD 2	MD 3
Age Band 1	Posting coins	Threading beads	Drawing Trail
Age Band 2	Placing pegs	Threading lace	Drawing Trail
Aiming and Catching	A&C 1	A&C 2	
Age Band 1	Catching Bean Bag	Throwing Beanbag onto mat	
Age Band 2	Catching Ball from Wall	Throwing Beanbag onto circle on mat	
7 – 8 yrs.	With bounce		
9 - 10yrs.	No bounce		
Balance	Bal 1	Bal 2	Bal 3
Age Band 1	One leg Balance (both legs)	Walking heels raised alone a line	Jumping onto mats
Age Band 2	One leg Balance on board (both legs)	Walking heel to toe alone a line	Hop onto the Mat

Table 6.3. shows the tasks used to assess each of the three areas for age band one and two of the MABC-2 Test. Manual dexterity (MD) is the ability to use the hands to complete coordinated, precise movements to meet the demands of a task. The manual dexterity component of the MABC-2 assesses the areas of unilateral (one handed) coordination in MD 1, bilateral (two handed) coordination in MD 2, as well as pen control in MD 3. MD 1 and MD 2 are scored on time taken to complete the task, MD 3 is scored on accuracy. Catching requires the ability to coordinate the two sides of the body, to plan and adapt body position based on the oncoming object and aiming requires coordinating the eyes and hands effectively to throw towards a target. Table 6.3. shows the tasks used to assess aiming and catching in the MABC-2. The balance component of the MABC-2 Test assesses aspects of static (stationary) balance in Bal 1 and dynamic (moving) balance in Bal 2 and Bal 3. Bal 1 is assessed by the number of seconds balance is maintained, Bal 2 is measured as the number of correct steps taken and Bal 3 is measured as the number of correctly performed sequential jumps/hops out of five.

The sum of the standard scores for the individual tasks in each component is converted into a component standard score (manual dexterity, aiming and catching and balance). The sum of the three component standard scores are converted into a total standard score for the entire test (M = 10, SD = 3). The MABC-2 Test has UK norms from 2007, and has been reported to have good test re-test reliability coefficients for the total test score (.80) as well as for component scores (.73-.84) (Henderson et al., 2007). The MABC-2 Test has also been found to have good-excellent interrater reliability and fair to good construct and concurrent validity with the Bruininks-Oseretsky Test of Motor Proficiency 2nd Edition (BOT-2) (Bruininks & Bruininks, 2005) (Blank et al., 2019). There are some limitations of the MABC-2 test such as the lack of sensitivity to top end performance, and the requirement of different tasks for different age ranges effecting the ability to directly compare performance across the same task longitudinally or use raw scores across groups to increase sensitivity in research. However, the MABC-2 is still the recommended assessment to provide evidence for Criterion A of the DSM-5 diagnostic criteria in the UK, in both clinical and research settings (Blank et al., 2019).

6.2.2.2. Movement Assessment Battery for Children 2nd Edition (MABC-2) Checklist (Henderson et al., 2007). The MABC-2 Checklist is a standardised questionnaire with UK norms for children aged five to twelve years which assesses movement performance in a child's everyday activities and takes approximately 10 minutes to complete. In the standardisation checklists were completed by teachers, however, the checklist can also be completed by a parent/carer. The Checklist has a total of 30 items, divided into section A and B with 15 items in each. Section A measures self-care, classroom and Physical Education (P.E.) skills in a predictable environment; section B measures self-care, ball and P.E. skills in an unpredictable environment. The rater marks each item on a 4-point scale ranging from 0 = very well to 3 = not close. Scores from section A and B are summed to produce a total motor score, with higher scores indicating poorer performance. Percentiles and cut off scores are provided for each age. Scores that fall above the 95th percentile indicate significant difficulties in everyday tasks that require motor skills. A high Cronbach alpha (.94) suggests that all 30 items assess an aspect of motor performance (Schoemaker et al., 2012).

6.2.2.3. Developmental Coordination Disorder Questionnaire (DCDQ) (Wilson et al., 2009). The DCDQ is a short parent/carer questionnaire designed to screen for DCD in children aged five to fifteen years. It takes approximately 10 minutes to complete. Parents/carers rate their child's performance on 15 items which assess the three areas of control during movement, fine motor/handwriting tasks and general coordination. A total score is used to indicate whether the child shows an indication of DCD or not within age specified cut-offs. The total scores range from 15 to 75 and have a mean of 61.79 with a standard deviation of 10.21 (Wilson & Crawford, 2012). The DCDQ's sensitivity in correctly identifying children with DCD is 84.6% and it has a moderate correlation (.55) to the MABC-2 Test (Henderson et al., 2007) (Wilson et al., 2009). Good test retest reliability has been found in the Brazilian (.97) (Prado et al., 2009) and Chinese (.94) (Tseng et al., 2010) adaptation of the DCDQ but has not been assessed in the English version. Moderate correlations have been found between the MABC-2 Checklist and the DCDQ (0.36) indicating that the questionnaires overlap but also measure different motor skills (Schoemaker et al., 2012). Both the DCDQ and MABC-2 Checklist are used to identify parent/carer and teacher concerns but are not recommended for screening purposes according to the International Guidelines for DCD.

6.2.2.4. British Picture Vocabulary Scale 3rd Edition (BPVS-3) (Dunn et al., 2009). The IDS-2 Intelligence domain was administered to all children, however, as standard scores were not available the BPVS-3 was also administered. The BPVS-3 was used to obtain a measure of receptive vocabulary which correlates highly with verbal IQ (Glenn & Cunningham, 2005). The BPVS-3 has a moderate to good positive correlation to the Cognitive Abilities Test (CAT) (.61-.72) a UK test which is usually used with school children which assesses cognitive skills such as reasoning and problem solving (Dunn et al., 2009). The BPVS-3 is frequently used within DCD research as part of a diagnostic assessment to indicate the absence of a broader developmental delay which could better explain potential movement difficulties (Criterion D). A benefit of using the BPVS-3 with children with DCD is that it does not require a motor response which could impact performance. The assessment was conducted face to face with the child and took approximately 10 minutes. The child was presented with a series of pages with four pictures on a page, when the tester said a word, the child was required to identify the picture that best represented the word. The BPVS-3 is a standardised test with UK norms. Raw scores are converted into standard scores (M = 100, SD = 15). The inclusion criteria were set as a standard score of at least two standard deviations from the mean (≥ 70). The BPVS-3 standardisation did not account for variables such as household income, languages spoken at home or parent/carer education level. Therefore, a cut-off of two standard deviations from the mean was reasoned to be more appropriate than the more stringent 1 standard deviation so children were not unduly discounted.

6.2.2.5. Supplementary Measures.

6.2.2.5.1. Strengths and Difficulties Questionnaire (SDQ) (Goodman & Goodman, 2009). The SDQ (Goodman & Goodman, 2009) is a parent/carer completed measure of behavioural difficulties. This questionnaire takes approximately 10 minutes to complete. It includes questions regarding both positive and negative attributes and behaviours in five areas: conduct, hyperactivity and inattention, emotional control, peer relationships and pro-social behaviour. A child is given a score for each of the five areas and the scores from the first four are summed to give a total difficulties score. These scores can then be classified into bandings based on a UK community sample. For the first four categories and the total score approximately 80% of children scored ‘close to average’, 10% ‘slightly raised, 5% ‘high’ and 5% ‘very high’. The hyperactivity and inattention score was used in additional analysis for Study One, which is provided in Appendix B.

6.2.2.5.2. Demographic Information Questionnaire. Parents/carers also completed a questionnaire to provide demographic information. This asked about the child’s ethnicity and parent/carer education level. Parents/carers were also asked to report any known diagnoses their child had. This information helped to provide a more detailed description of the characteristics of the overall sample. It allowed for the examination of potential differences between the groups on demographic factors and consideration of the generalisability of the findings to the wider UK population.

6.2.3. Participant Information on Selected Measures

6.2.3.1. Demographic Information for DCD and TD Groups. Table 6.4. displays the demographic information for each group. Taking both groups together the proportion of White British children (80%) and Ethnic Minorities (20%) included in the study is in line with the 2011 census (80.5%; 19.5%) (Office for National Statistics; National Records of Scotland; Northern Ireland Statistics and Research Agency, 2016). The education level of parents/carers in this sample is higher than the UK average. 71% of mothers and 50% of fathers (who reported their information) achieved a higher education level (≥ A levels), compared to 42% of the UK population aged 21 to 64 (Office for National Statistics, 2017). The two groups were roughly matched on ethnicity. The DCD group included slightly more white-British children (88%) compared to the TD group (72%), slightly lower levels of parent/carer education (54% of parents/carers in the DCD had the minimum of an undergraduate degree compared to 64% of parents/carers of TD children), and fewer children in the DCD group lived with both parents/carers.

Table 6.4.

Demographic Information for Children with DCD the TD Control group

		DCD	TD
Gender	Male	23	23
	Female	2	2
Age (years, months)	Mean (SD)	8yrs 8m (1yr, 3m)	8yrs 8m (1yr, 2m)
	Range	6yrs 2m – 10yrs 11m	6yrs 4m – 10yrs 9m
Ethnicity	White – British	22	18
	Asian – Pakistani, Bangladeshi, Chinese	2	4
	Black -Caribbean, African, other	1	
	Other		3
% Living with female and male guardian		79%*	100%
Maternal education	5 GCSE's or less	3	1
	Up to A level	4	6
	Undergraduate Degree	13	15
	Postgraduate Degree	4	3
	Unknown	1	
Paternal education	5 GCSE's or less	3	3
	Up to A level	7	7
	Undergraduate Degree	8	11
	Postgraduate Degree	2	3
	Unknown	5	1

Note: * n = 24 due to missing data

6.2.3.2. BPVS and SDQ Results for DCD and TD Groups. Table 6.5. shows the scores from selected measures for each group. Where appropriate group differences were examined statistically. When assumptions of normal distribution and equality of variance were met for each group, parametric t tests were used otherwise the non-parametric alternative Mann-Whitney U test was used. There were no significant differences between the groups on BPVS-3, with both groups scoring very close to the mean (100). Children with DCD had higher rates of hyperactivity and inattention on the SDQ compared to TD peers. Using the SDQ UK population survey categories, the mean hyperactivity score for the TD group fell within the ‘average’ range, whereas the mean hyperactivity score for the DCD group fell at the top boundary of the ‘slightly raised’ category. Out of the 25 children with DCD, 19 had ‘slightly elevated’ or higher scores for hyperactivity and inattention, indicating potential difficulties in these areas. This indicates that the children in the DCD group not only had higher hyperactivity and inattention scores than the TD control group used in this research but that they also had higher scores compared to the wider UK population. Crane, et al., (2017) also found that children with DCD had significantly higher hyperactivity and inattention scores on the SDQ questionnaire compared to a TD control group.

Table 6.5.

Mean Scores for DCD and TD groups on Selected Measures

Selected Measures		DCD	TD	p
BPVS-3 Standard Score		103.52	*101.52*	*.62*
SDQ Hyperactivity Score		7.16	2.56	< *.001*
Co-occurring ASC	(№ children)	7	0	
Co-occurring ADHD	(№ children)	2	0	

6.3. Standardised Measures and Experimental Tasks

6.3.1. Standardised Measures of Motor Skills.

To obtain a comprehensive profile of children’s motor skills, two assessment batteries were completed, as outlined below.

6.3.1.1. MABC-2 Test (Henderson et al., 2007). See section 6.2.2.1.

6.3.1.2. The Intelligence and Development Scales for Children and Adolescents 2nd Edition (IDS-2) (Grob & Hagmann-von Arx, 2017) Psychomotor Component. The IDS-2, originally published in German, is a comprehensive battery of assessments assessing domains including: Intelligence, Executive Function, Psychomotor skills, Social-Emotional skills, Scholastic skills, Motivation and Attitude. The research for this thesis was part of the IDS-2 UK standardisation project taking place between 2017-2020. The IDS-2 is designed for children aged five to adults aged twenty years. Clinically, the IDS-2 Psychomotor component is useful because it extends the upper age limit of the MABC-2 (which is the most used assessment of motor skills in the UK) from 16 years to 20 years. It takes approximately 20 minutes to complete and assesses three areas of motor skills: gross motor, fine motor and drawing skills and provides separate measures for speed (time) and accuracy (quality). This provided additional information to the MABC-2 to create a broader profile of motor skills. As the UK standardisation was underway during this project and standard scores were not yet available, only point scores are reported for the IDS-2.

Table 6.6.

IDS-2 Psychomotor Tasks

Component	Tasks			Max Score
Gross Motor	1	2	3	
	Walking heel to toe alone a rope with eyes open and eyes closed	Throwing and catching a ball five times	Jumping to and fro over a rope as many times as possible in ten seconds	
Maximum points available	8	8	8	24
Fine Motor	1	2		
	Screw and unscrew nuts from bolts of three sizes	Thread three different sized beads onto string		
Maximum points available	Time 30 Quality 18	Time 30 Quality 18		96
Visuomotor	1	2	3	
	Four drawing trails	Copy four images	Complete four Mirror images	
Maximum points available	Time 16 Quality 8	Time 24 Quality 40	Time 24 Quality 20	132

Table 6.6. outlines the tasks used to assess each area. Performance for gross motor skills is scored out of 24, with points awarded based on the accuracy of walking along a rope, the number of successful catches and quality of throwing a small foam ball, and the number of jumps over a rope in ten seconds. Separate time and quality scores are given for both fine motor and visuomotor (drawing) performance. A total of 60 points for time and 36 points for quality are available for fine motor performance and a total of 64 points are available for time and 68 for quality for visuomotor (drawing) performance. Higher point scores indicate better performance.

6.3.1.3. Motor Performance of DCD and TD Groups. As mentioned earlier in Table 6.1 all children with DCD had MABC-2 Checklist scores in a range indicative of significant motor difficulties. The mean total MABC-2 Checklist score was 31.25 (SD = 12.96). All children with DCD also had a DCDQ score indicative of DCD (Mean 32.58, SD = 8.94). Table 6.7. displays the means, and standard deviations for each group on the other motor measures and statistical tests of group differences. When assumptions of normal distribution and equality of variance were met for each group, parametric t tests were used, otherwise the non-parametric alternative Mann-Whitney U test was used. Children with DCD performed significantly more poorly than TD children on all measures of motor skills excluding the IDS-2 Psychomotor Visuomotor Time score. The MABC-2 Test total scores were used as inclusion criteria for the groups, so it is unsurprising that there are significant differences in these scores. Children with DCD have poorer motor skills than those without, however, the nature of these difficulties is heterogenous (e.g. one child may have poor fine motor skills and average ball skills whereas another may have average fine motor skills and poor ball skills). The finding that children in the DCD group had significantly poorer scores on all components of the MABC-2 Test and IDS-2 Psychomotor component (except IDS-2 visuomotor time) indicates that overall the DCD group had poorer motor skills in all areas assessed. Children with DCD were found to have significantly poorer scores on the IDS-2 Visuomotor accuracy score but not the IDS-2 Visuomotor time score. This suggests that children with DCD focused on speed to the detriment of accuracy on this task.

Table 6.7.

Performance on Measures of Motor Skills for Children with DCD and the TD Control group

Motor Measures	DCD (Mean, SD)	TD (Mean, SD)	U/t	p
MABC-2 Test Overall Score SS	4.04 (1.84)	10.40 (2.36)	*U 0.00*	*≤ .001*
MABC-2 Test Manual Dexterity SS	5.92 (3.38)	10.7 (2.48)	*U 74.00*	*≤ .001*
MABC-2 Test Aiming and Catching SS	6.04 (2.32)	10.70 (2.75)	*U 58.50*	*≤ .001*
MABC-2 Test Balance SS	4.88 (2.76)	10.00 (3.26)	*U 69.50*	*≤ .001*
IDS-2 Fine Motor Time (IDS-2-FM-T) Points	19.48 (8.56)	25.40 (7.31)	*t 2.65*	*.011*
IDS-2 Fine Motor Quality (IDS-2-FM-Q) Points	19.64 (6.61)	26.70 (5.48)	*t ≤4.00*	*≤ .001*
IDS-2 Gross Motor (IDS-2-GM) Points	8.92 (4.81)	16.60 (4.27)	*U 76.50*	*≤ .001*
IDS-2 Visuomotor Time (IDS-VM-T) Points	45.04 (11.59)	42.70 (14.08)	*t .65*	*.521*
IDS-2 Visuomotor Quality (IDS-VM-Q) Points	31.20 (9.67)	43.00 (11.28)	*t 3.99*	*≤ .001*

Note: SS – standard score

6.3.2. Standardised Measures of Executive Function

6.3.2.1. IDS-2 Executive Function Component (IDS-2-EF) (Grob & Hagmann-von Arx, 2017). The IDS-2-EF is part of the broader IDS-2 test battery for people aged five years to twenty years. The Executive Function component consists of four tests assessing the areas of: Inhibition (Response Inhibition and Interference Control), Mental Flexibility, Working Memory, and Planning. Table 6.8. outlines the four IDS-2-EF tasks: 1. 'Listing Words' requires participants to list lots of different words from a category (e.g. animals), 2. ‘Divided Attention’ requires participants to complete two activities simultaneously: crossing out parrots that conform to a set rule on a sheet including distractor parrots that do not conform and at the same time list different animals. 3. ‘Animal Colours’ – requires saying correct animal colours despite their presenting colour and 4. ‘Drawing routes’ requires participants to plan and complete mazes quickly without lifting the pen or retracing sections. Table 6.8. describes how some of the task requirements increase in complexity for older children. These four tasks assess the four components of Executive Function combined; however, each task does have a different primary focus (e.g. Listing Words primarily assesses mental flexibility). The IDS-2-EF takes approximately 30 minutes to administer. At the time of writing, the UK IDS-2 standardisation was currently underway, and reliability and validity data were not available in English. Data from the German and Dutch standardisation projects show significant differences in IDS-2 EF between typically developing children and those with ADHD (when not on medication). They also report significant correlations between IDS-2-EF and elements of the Test of Everyday Attention for Children (TEA-CH; Horn & Jager, 2008), the Trail Making Test (TMT; Reitan, 1992), Stroop (Stroop, 1935), and the Behavior Rating Inventory of Executive Function (BRIEF; Gioia et al., 2005).

Table 6.8.

IDS-EF Tasks

Task	Requirements	Age	Primary area assessed
Listing Words	List as many words as possible from a category in 90 seconds. There are two trials 1) Animals 2) Fruits and vegetables. A score is provided for the total number of correct words listed.	5yrs – 8yrs	Mental Flexibility
	List as many words as possible in 90 seconds. There are four trials 1) From a particular category (animals) 2) From two categories alternately (vehicles, and fruits and vegetables) 3) Words beginning with a particular letter (F) 4) words beginning with different letters alternately (P and S). A score is provided for the total number of correct words listed.	10yrs +	
Divided Attention	Crossing out parrots that conform to a set rule on a sheet including distractor parrots that do not conform and at the same time list different animals. A separate score is provided for the number of parrots crossed out and the number of animals listed.	5yrs +	Mental Flexibility
Animal Colours	Animals are presented in three conditions: congruent (animals are the correct colour), grey (animals are grey) and incongruent (animals are the incorrect colour)*. Participants are required to say the correct colour of the animal as quickly as possible despite the presenting colour. Each condition has one page of 36 images, consisting of four animals (dolphin, frog, chick, ladybird) in a non-sequential order that is fixed for all participants. Time is measured in seconds and a total score is calculated as Total score = $incongruent\ time - \frac{(congruent \times grey)}{(congruent + grey)}$	5yrs +	Inhibition
Drawing Routes	Plan and complete increasingly complex mazes quickly without lifting the pen or retracing sections. A separate score out of 42 is provided for both time taken and quality. Time includes 'planning' plus drawing time.	5yrs +	Planning

Note: ***** Data from the third, 'incongruent condition' of the 'Animal Colours' task was also used as a measure of 'Interference Control', as described under the 'Experimental Tasks Measuring Inhibition' section 6.3.3 and referred to as AdAC – an adaptation of the Animal Colours task.

6.3.2.2. Behavior Rating Inventory of Executive Function (BRIEF-2) – Parent/Carer and Teacher Questionnaires (Gioia et al., 2015). The BRIEF-2 is a standardised questionnaire with separate parent/carer and teacher forms which take approximately 10 minutes to complete. The BRIEF-2 has US norms for children aged five years to eighteen years and assesses everyday behaviour associated with Executive Function. The questionnaire contains 63 items that cover nine domains of Executive Function (Inhibit, Self-Monitor, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Task-Monitor and Organization of Materials). The first 57 questions are identical between the parent/carer and teacher forms with six questions that are specific to each. On the parent/carer forms these six statements cover the areas of Organization of Materials, Initiate, Plan/Organize, Inhibit and two questions for Shift. On the teacher form these six statements cover the areas of Self-Monitor, Task-Monitor, Plan/Organize, Inhibit and two questions on Shift.

A parent/carer and/or teacher rates each statement on a 3 point scale (1-3) according to whether the behaviour occurs 'never, sometimes or often'. Table 6.9. outlines the different measurements that are obtained from the BRIEF-2 parent/carer and teacher questionnaires. Individual 'scale scores' are obtained for each of the nine domains listed above. Scores are also summed to gain three 'index scores': the Behavioural Regulation Index, which represents a child's ability to effectively regulate and monitor their behaviour (the sum of the Inhibit and Self-Monitor scales); the Emotional Control Index, which represents a child's ability to regulate emotional responses including responding to changing circumstances (the sum of the Shift and Emotional Control scales) and the Cognitive Regulation Index, which represents a child's ability to control and manage cognitive processes (the sum of the Initiate, Working Memory, Plan/Organize, Task-Monitor and Organisation of Materials scales). All scale scores are also summed to gain a 'Global Executive Composite' score which represents overall ability related to Executive Function.

Scale, Index and the Global Executive Composite raw scores are converted into T scores which have a mean of 50 and a standard deviation of 10. In the US standardisation sample T scores of 59 or lower are considered within the 'typical range', 60-64 are 'mildly elevated', 65-69 are 'potentially clinically elevated' and

70+ are 'clinically elevated'. There are no normative data for the UK population, however, a review of BRIEF 1st edition scores across English speaking countries (Australia, Canada, Israel, UK and US) found no significant difference on the Global Executive Function Composite scores (Roth et al., 2015). However, domain specific and index scores were not reported and only two UK studies were included in the review.

Table 6.9.

A Summary of the BRIEF-2 Scales, Index and Global Executive Function Composite

Scale	Description
Inhibit	The ability to control behaviour and not act on impulse.
Self-Monitor	The ability to understand the consequences of actions.
Behavioural Regulation Index	The sum of Inhibit and Self-Monitor scales, represents a child's ability to effectively regulate and monitor their behaviour.
Shift	The ability to think flexibly and move from one task to another when necessary.
Emotional Control	The ability to control and regulate emotions.
Emotional Control Index	The sum of the Shift and Emotional Control scales and represents a child's ability to regulate emotional responses including responding to changing circumstances.
Initiate	The ability to begin tasks, generate ideas and problem solve.
Working Memory	The ability to hold information in memory for a short time to complete a task.
Plan/Organize	The ability to manage current and future task demands.
Task-Monitor	The ability to notice minor errors in work.
Organization of Materials	The ability to organise belongings and workspace.
Cognitive Regulation Index	The sum of initiate, working memory, plan organise, task-monitor and organisation of materials and represents a child's ability to control and manage cognitive processes.
Global Executive Composite	An overall summary score that incorporates all the index scores, representing overall ability in Executive Function.

The BRIEF-2 is based on the Unity and Diversity model of Executive Function (Miyake et al., 2000), which was outlined in detail in chapter three (section 3.2.). This model conceptualises Executive Function as distinct components that share underlying commonality. Clinical interviews with parents/carers and teachers were used to capture common everyday behaviours associated with Executive Function. The high agreement rate between a team of paediatric neuropsychologists regarding items within each scale provided evidence that items accurately measure the intended construct. Intercorrelations between the scales range from .41-.88 for the parent/carer and teacher forms (Gioia et al., 2015). This provides evidence that the scales measure separate but related constructs.

Confirmatory factor analysis (CFA) was used to assess the internal structure of the BRIEF-2: how items fit into scales, how scales fit into indexes and how all three interrelate. The CFA found the three-factor model, based on the index scores, fit acceptably well with Comparative Fit Index (CFI) ranging from .95 -.99 across the parent/carer and teacher forms. Values of .95 represent acceptable fit (Hu & Bentler, 1995). Jiménez and Lucas-Molina, (2019) also found an acceptable fit with the three-factor model (CFI .97) for the Spanish version of the BRIEF-2. The BRIEF-2 scales and indexes have also been compared against widely used behaviour rating scales to provide further evidence of validity (e.g. the Child Behaviour Checklist, (Achenbach, 1991)). These showed a pattern of convergent and discriminative relationships with moderate correlations found for items that are expected to have greater theoretical overlap (Gioia et al., 2015).

Interrater reliability of the BRIEF-2 has been examined across raters who encounter a child in the same environment (home-home, and school-school) as well as in different environments (home-school). Correlations between parent/carer and teacher ratings of the same child were moderate with an overall mean correlation across the scales, indexes and Global Executive Composite of .64 for the standardisation sample, and .34 for the clinical sample. Moderate overall correlations were also found between parent/carer raters (.77 for the standardisation sample and .59 for the clinical sample) and between teachers (.39 for the standardisation and .56 for the clinical sample). Low interrater reliability coefficients are common on questionnaire measures of children's behaviour (De Los Reyes & Kazdin, 2005). This could be because behaviour is influenced by personal relationships and environmental demands. This highlights the importance of using both a teacher and a parent/carer form to gain a broader understanding of a child's profile of Executive Function across different environments. Test-retest reliability coefficients of ≥ .79 for scales, indexes and the Global Executive Composite provides evidence that results are reasonably stable over repeated administrations.

The Inhibit scale of the BRIEF-2 is of particular relevance to Study One and Two. Table 6.10. outlines items from the parent/carer and teacher forms which inquire about everyday behaviour requiring Inhibition skills. Each form has eight statements, seven are identical and one is specific to each form. Internal consistency coefficients for the Inhibit scale range from .86 -.93 across the parent/carer and teacher forms for the clinical and standardisation sample, this suggests good agreement between the items in the scale. The Inhibit scale shows good correlations with the Behaviour Assessment System for Children 2nd edition's (Reynolds & Kamphaus, 2004) measure of hyperactivity and (.81) moderate correlations with its measure of attention problems (.54). The scale has moderate-good inter-rater reliability: parent/carer and teacher correlations range from .71 for the standardisation sample and .49 for the clinical sample; agreement between parents/carers ranges from .75 for the standardisation sample and .67 for the clinical sample and agreement between teachers is .43 for the standardisation sample and .67 for the clinical sample.

Table 6.10.

BRIEF-2 Inhibit Scale Statements for Parent/Carer and Teacher Forms

Statement	Form statement appeared in
Is fidgety	*Parent/Carer & Teacher*
Does not think before doing (is impulsive)	*Parent/Carer & Teacher*
Gets out of control more than friends	*Parent/Carer & Teacher*
Talks at the wrong time	*Parent/Carer & Teacher*
Gets out of seat at the wrong time	*Parent/Carer & Teacher*
Acts too wild or out of control	*Parent/Carer & Teacher*
Has trouble putting the brakes on his or her actions	*Parent/Carer & Teacher*
Does not think of consequences before acting	*Parent only*
Becomes too silly	*Teacher only*

6.3.3. Experimental Tasks Measuring Inhibition

As outlined in Chapter two Inhibition can be separated into Response Inhibition and Interference Control (Nigg, 2000). For this research experimental tasks have been adapted to measure Response Inhibition and Interference Control in tasks that require both a motor and a verbal response. To build on and assist with comparison of results to previous literature, where possible these measures are tasks/adaptations of tasks that have previously been used to assess the Inhibition skills of children with DCD (See chapter four) (AdVIMI motor, AdVIMI verbal, AdFlanker motor). The only exception is use of the AdAC, an adaptation of the IDS-2 'Animal Colours' task described in Table 6.8 above. This was included to provide an Interference Control task with a verbal response. The AdAC has similar task demands to the Fruit Stroop task which has previously been used to assess Interference Control in children with DCD (Michel et al., 2011).

6.3.3.1. Verbal and Motor Response Inhibition Task: AdVIMI. The Verbal Inhibition Motor Inhibition 'VIMI' task is an experimental task designed by Henry, Messer, and Nash, (2012) to assess Response Inhibition in children aged 6-14 years. The task was originally designed to be used for both typically developing children and children with specific language impairments (now referred to as Developmental Language Disorder (DLD) (Bishop et al., 2017). This required the task to be carefully designed to ensure that the language and instructions were easily understood and that the task was measuring response Inhibition rather than language skills.

This task had two parts: 'part A' (the congruent condition) required the child to copy what the tester said or did and 'part B' (the incongruent condition) required the child to inhibit the copy response and respond with a paired opposite word or action. In total there were eight verbal blocks consisting of 160 trials and eight motor blocks consisting of 160 trials. In the verbal condition 80 trials (four blocks) used the words 'doll' and 'car' and 80 trials (four blocks) used the words 'bus' and 'drum', in the motor condition 80 trials (four blocks) used the actions of a horizontal hand and vertical hand and 80 trials (four blocks) used a pointed finger and a fist.

As outlined in chapter three, the VIMI task has also been used to investigate Response Inhibition in children with DCD (Bernardi et al., 2016; Leonard et al., 2015). These studies calculated the error rate of the verbal and motor Inhibition tasks separately. Bernardi et al. (2016) also calculated total completion time for the verbal and motor tasks separately by recording the time taken to complete each block and summing the eight verbal and eight motor blocks separately. Internal consistency measured by Cronbach's alpha on total error scores from the copy and the inhibit blocks were .92 for the motor task and .73 for the verbal task indicating that the items were measuring the same construct.

To meet the aims of this research the VIMI was adapted and will be referred to as the AdVIMI, Table 6.11 provides a summary of the adaptations made. These changes were designed to increase the sensitivity of the measure and control for potential confounding variables such as attention and presentation style. The final presentation and scoring format was confirmed following extensive trialling and piloting.

The key change was to reduce the length of time required to complete the task by 75%, from 320 trials to 80 trials so that the task could be completed in approximately 10 minutes. The AdVIMI had one copy (congruent) and one inhibit (incongruent) block with 20 trials each for the verbal (target words: 'car' and 'doll') (see Figure 6.1.) and the same for the motor tasks (target actions: finger and fist) (see Figure 6.2.). The verbal stimuli were chosen from the first condition of the VIMI. Due to the subtlety of the motor response required in the first VIMI motor condition (horizontal hand, vertical hand), and the difficulty children with DCD encounter with accuracy of movement, it was decided to take the stimuli from the second condition of the VIMI (fist, finger). This increased the accuracy of the scoring as it is clearer which position the child is attempting even if it is not performed with total accuracy (e.g. two fingers pointed, rather than one). The overall reduction in the number of trials decreases the degree to which attention or working memory (e.g. child forgetting if the trial was 'copy' or 'inhibit') could impact the results.

The original VIMI was presented with the experimenter sitting in front of the child; in the verbal task the experimenter would provide an auditory stimulus to the child by saying a word whereas in the motor task the experimenter would provide a visual stimulus to the child by performing an action. In the AdVIMI the presentation was changed to a Microsoft PowerPoint presentation on a computer monitor. This meant that the child always responded to a visual stimulus e.g. picture of a hand gesture, picture of a doll/car (see Figures 6.1. and 6.2.). This uniform presentation enhanced the comparability of the results from the verbal and motor tasks. In between each trial slide in the verbal task there was a plain white slide; in between each trial slide for the motor task there was a slide with a picture to remind the child to place their hands back onto the mat (see Figure 6.3.). Timing of the presentation of slides was controlled manually by the tester. Children were informed of the rules of the task and asked to 'say the word' or 'move' as quickly as possible for the verbal and motor tasks respectively. Appendix C details the full instructions given, these were kept as similar as possible to the instructions of the VIMI.

Each child's performance in the testing sessions was audio and video recorded so that the scoring of each trial could be completed off-line. Recording the tasks also enabled the sensitivity of the measure to be increased by gathering data on both Reaction Time (RT) and Movement Time (MT). The verbal task recordings were transferred into 'Wave Editor' software to enable RT to be recorded in milliseconds. The videos of the motor tasks could be slowed, and reaction and MT recorded in milliseconds.

6.3.3.1.1. AdVIMI Scoring. The verbal task was measured using the mean trial RT (measured in milliseconds) and total error rate. The motor task was measured using mean trial RT (measured in milliseconds), mean trial MT (measured in milliseconds) and total error rate. For the verbal task RT was defined as the time from stimulus display to the first sound of the first attempted response. For the motor task RT was defined as the time from the stimulus display to movement towards a purposeful response (e.g. a finger twitch or whole hand movement), and MT was defined as the time taken after the RT to when a child's hand was still, in position (fist or finger). Qualitative observations of how children moved were also noted and responses were coded according to how the child's hand left the mat (e.g. whole hand moved in unison, one finger moved first). This was because the signal for RT differed depending on the movement type (e.g. a finger sliding backwards, or a whole hand simultaneously moving up). Coding the responses enabled comparison between the groups to assess if there was a systematic difference in how the groups responded, which could have had an effect on RT (e.g. if the child did not replace their hand on the mat and the movement started in mid-air). The sensitivity of both the verbal and motor task was also increased by introducing the ability to mark ‘self-corrected responses’ when a child initially answered incorrectly and then corrected themselves. Errors were marked zero to two with zero representing a correct response, one a self-corrected response and two an incorrect response. A higher error rate is an indication of poorer performance. Appendix D outlines the scoring criteria for the verbal and motor conditions including the codes for movement categorisation. Videos of performance across all conditions were viewed to identify the range of potential hand movements that could be made and to develop a set of scoring criteria. By the time that 31 full sets of videos had been viewed, no new hand movements were observed and the scoring criteria were fully developed. The 31 sets were remarked once the scoring criteria had been finalised.

***6.3.3.1.2. AdVIMI Piloting*.** The AdVIMI was piloted on eleven adults and two children aged four and five years old. This enabled the instructions to be simplified and the correct equipment chosen for recording and scoring. Following piloting the original lower age band for participants was raised from five to six years as the children aged four and five were unable to complete the full task. Different cameras were trialled, and the task was split into two PowerPoint presentations (verbal and motor) rather than one. This was to reduce the file size and prevent the PowerPoint from crashing during the task. The task was piloted on several participants using a standardised timed presentation of the slides, however, this was not found to be practical. For the measurements of RT and MT for the motor component a child’s hands needed to start flat on the mat. Within the timed presentation, not all participants had time to place their hands back onto the mat. Within the verbal task, some of the responses were missed or started on the wrong slide. Furthermore, the waiting time after responding was still not standardised as people responded at different times. Therefore, presentation was controlled by the tester and moved on after the child had either said the word or replaced their hands back onto the mat after completing an action.

Table 6.11.

Comparison between Original VIMI Presentation and Adaptations made for the AdVIMI used in the Current Studies

	Original VIMI Task	AdVIMI
Verbal Task		
Verbal - №, Blocks	8	2
Verbal - №, Test Items	160	40
Practice Items	No formal practice	4 practice items
Presentation Method	Modelling	Computer
Presentation Stimuli - Verbal	Audio	Visual
Scoring – Verbal	Error rate[1,2] Completion time[3]	Error rate Reaction Time
Error rate	Correct, Incorrect	Correct (0 points) Self-Corrected (1 point) Incorrect (2 points)
Presentation order	Fixed order for all	Same fixed order as original study.
Motor Task		
Motor -№, Blocks	8	2
Motor - №, Test Items	160	40
Practice Items	No formal practice	4 practice items
Presentation Method	Modelling	Computer
Presentation Stimuli – Motor	Visual	Visual
Scoring – Motor	Error rate[1,2] Completion time[3]	Error rate Reaction time Movement time
Error rate	Correct, Incorrect	Correct (0 points) Self-Corrected (1 point) Incorrect (2 points)
Presentation order	Fixed order for all	Same fixed order as original study.

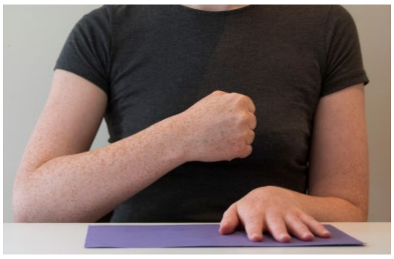
Note: Different research articles measured performance on the VIMI in different ways, these are highlighted in the table: [1] - Henry et al. (2012); [2] - Leonard et al. (2015); [3] - Bernardi et al. (2016)

Figure 6.1.

Images of the Target Words 'Doll' and 'Car' used in the Verbal Copy and Inhibit Tasks in the AdVIMI

Figure 6.2.

Images of the Target Actions used in the Motor Copy and Inhibit Tasks in the AdVIMI



'Fist'

'Finger'

Figure 6.3.

Image Shown in Between Motor Trials to Remind the Child to Replace their Hands onto the Mat

6.3.3.2. Motor Interference Control Task: AdFlanker. The Flanker task is a widely used measure of Interference Control. In the original Flanker task (Eriksen & Eriksen, 1974) adult participants saw a target letter (e.g. H, K, S or C) appear on a screen, either on its own (neutral condition) or with three letters flanking it either side, in one of five different conditions. Participants were required to give a directional response to the target letter, which would appear in the middle of the screen and pull a right lever for letters H and K and a left lever for letters S and C. For example, with the letter "H" as the target letter it could appear in the following conditions:

1. The target flanked by the same letter (e.g. HHHHHHH)
2. The target flanked by a letter requiring the same directional response (e.g. KKKHKKK)
3. The target flanked by a letter requiring the opposite directional response (e.g. SSSHSSS)
4. The target flanked by letters with similar visual features to the target letter (e.g. NWZHNWZ)
5. The target flanked by letters with dissimilar visual features to the target letter (e.g. GJQHGJQ)

Eriksen and Eriksen (1974) found that participants took longer to respond to a target that was flanked by letters requiring a different directional response (incongruent condition) compared to a target that was presented alone (neutral condition) or flanked by letters that required the same directional response (congruent condition). This was called 'the flanker effect' and it was concluded that responding during an incongruent condition requires the use of Inhibition.

The Flanker task has since been widely used as a measure of Interference Control in children, and several adaptations to the task have been created (see Appendix E). These adaptations typically have only two conditions: Congruent and Incongruent (Bervoets, et al., 2018; Gershon, et al., 2009; Konijnenberg & Fredriksen, 2018; McDermott, et al., 2007). However, some also include a neutral condition (Johnstone & Galletta, 2013; Rueda et al., 2004). Adaptations also differ in many other ways such as: the stimuli chosen, the length of time the images are displayed, the ratio of congruent to incongruent conditions, the inclusion of practice trials, fixation and warning images and the order of presentation (see Appendix E). Some adaptations, including the NIH Toolbox Flanker (Gershon et al., 2009) include ‘a priming effect’ in which the flanker stimuli are shown briefly prior to the target. This priming effect provides an opportunity to more effectively activate the Interference Control process because it enables processing in greater detail (Flowers, 1990).

For the current research, following a review of the Flanker protocols used with children, an adaptation of the NIH Toolbox Flanker task (Gershon, et al., 2009) was created using the software PsychoPy (see Figure 6.4.). The NIH Toolbox (mentioned in 3.4.2) is an American standardised battery of 48 assessment tasks measuring cognitive, emotional, sensory and motor functions in individuals aged three to eighty five years. The NIH Toolbox had a standardisation sample of 4205 people from across the United States including English and Spanish speakers. In a sub-sample of children aged three to fifteen years, from the standardisation sample, the NIH Toolbox Flanker task’s reliability and validity was assessed. It was found to have excellent test-retest reliability (ICC=.92) and moderate – good correlations with tasks assessing similar constructs. In a sample of 85 children aged eight to fifteen a moderate correlation was found with the colour word interference test from the Delis–Kaplan Executive Function System (Delis, et al., 2001) (r = .34) which assessed Inhibition. In a sample of 89 children aged three to six years a high correlation was found with the Wechsler Preschool and Primary Scale of Intelligence 3rd Edition (Wechsler, 2012) Block Design task (r = .60). Block Design requires a child to recreate a picture from a stimulus book using blocks and is a test of perceptual reasoning and motor coordination (Zelazo et al., 2013).

The NIH Toolbox does not allow access to raw score data and had a lack of consistency in the presentation of the stimuli. Therefore, adaptations to the NIH Toolbox Flanker were needed to enable detailed comparisons to be made between the groups. Adaptations that were made include using fish as the stimuli throughout the task and taking out the audio-cue of ‘middle’ as in piloting that was found to be a distraction. Appendix F outlines the full rationale for the AdFlanker design and Figure 6.4. displays the final presentation protocol. Appendix G details the full instructions given to the child, which explain the rules of the task and requests that the child “press the arrows as quickly as [they] can”. The task was presented on a touch screen; a child was shown five fish and instructed to press the arrow (black arrow on white background) which corresponded to the direction of the middle fish. In the congruent condition all the fish pointed the same way and in the incongruent condition the middle fish pointed a different way (see Figure 6.5.). Children had four practice trials (two congruent and two incongruent) for which they received feedback. A child needed to correctly identify three out of the four practice items or re-do the practice trials. If they failed to correctly identify three out of four practice items on the second occasion the session would have been terminated. This did not occur on any occasion during the study. Following successful completion of the practice items, children completed two blocks of twenty-five trials, each with 16 congruent and nine incongruent trials. There was a 1-minute break between the two blocks. The incongruent condition is the measure of Interference Control. This task meets the demands of an Interference Control task by presenting two domains (the target and the flankers) with only one relevant to the task (the target), the other acts as a distractor (the flankers) (Laloi et al., 2017).

Unlike the NIH Toolbox Flanker, the order of presentation was the same for each child in the AdFlanker. This is because it has been found that RT on incongruent trials are slower following a congruent trial and error rate is similarly effected (Gratton et al., 1992). The AdFlanker had one to three congruent trials preceding each incongruent trial. This elicited the largest ‘flanker effect’ in the shortest time and allowed for a fair group comparison (Zelazo et al., 2014).

6.3.3.2.1. AdFlanker Scoring. RT of each trial (measured in seconds) and total error rate were measured for the congruent and incongruent trials as well as RT and error rate difference between the congruent and incongruent conditions.

6.3.3.2.2. AdFlanker Piloting*.* *T*he AdFlanker was piloted on eleven adults prior to the protocol being finalised. Appendix F outlines the decisions made throughout this piloting process. These include the decision to keep the same number of trials and blocks as the original NIH Toolbox flanker, to present a fixation cross between trials for 100 milliseconds and to remove the audio cue that reminded participants to remain focused on the middle of the screen. The size of the touch screen arrow buttons were adapted during piloting due to some participants missing the button. The aim of this task is to assess Interference Control in the context of a motor response not to assess the precision of motor skills, therefore the size of the arrow buttons were increased. It was not possible to pilot with children before the start of the study. However, the second child to complete the AdFlanker within the project did not direct their attention to the screen at the start of the formal trial. Therefore, an adaptation was made to the instruction script after this to warn children that the task was about to begin (see Appendix G).

Figure 6.4.

AdFlanker Protocol Images for Congruent Condition

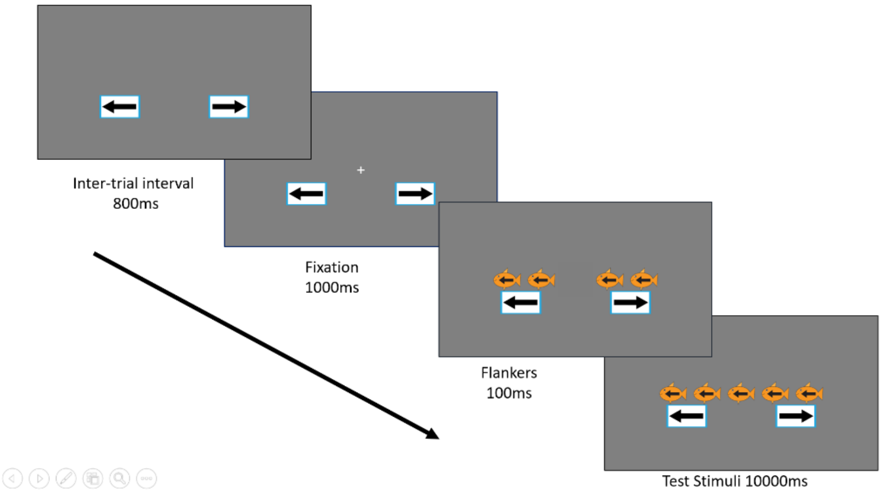
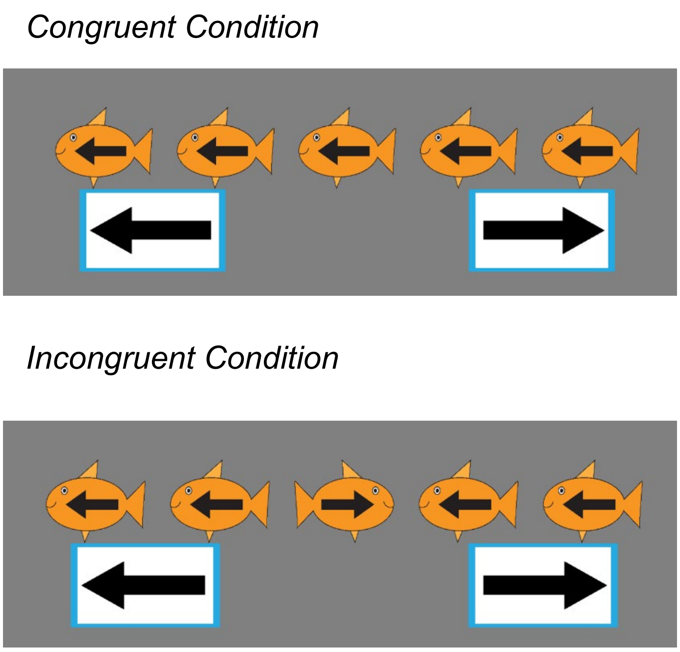


Figure 6.5.

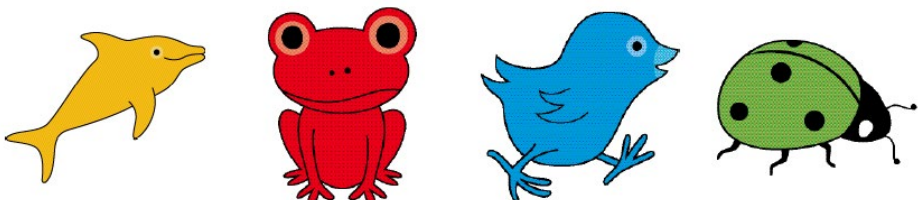
AdFlanker Congruent and Incongruent Images



6.3.3.3. Verbal Interference Control Task: AdAC For the verbal Interference Control task, the completion time and error rate from the third condition of the Animal Colours task from the IDS-2 (Grob & Hagmann-von Arx, 2017) was used, referred to here as AdAC. This measurement was used to isolate the effect of Interference Control. Children were asked to say the colour of the animal as quickly as possible despite it's presenting colour. The AdAC task is outlined in more detail below and in Table 6.8. Figure 6.6. depicts an example of the images and responses for the AdAC, taken from the third (incongruent) condition of the Animal Colours task. The time taken in seconds to complete the incongruent condition and the number of errors (which are not self-corrected) is used in this research as a measure of Interference Control which requires a verbal response. This task had the demands of an Interference Control task by presenting two domains (the animal shape and the animal colour) with only one relevant to the task (the animal shape), the other acts as a distractor (the colour) (Laloi et al., 2017). Ho and Wilmut (2010), in a study of the motor control of speech, did not find a difference between children with DCD and TD children in the production time of single words. Therefore, the motor difficulties of children with DCD should not affect their performance and the results should reflect Interference Control ability.

Figure 6.6.

Images for the AdAC, taken from the IDS-2-EF Animal Colours Task – Incongruent Condition



Correct Response:

Blue **Green** **Yellow** **Red**

6.4. Procedure

A summary of the experimental tasks is provided in Table 6.12. The tester presented the tasks in a game-like way to make the testing sessions enjoyable. Positive reinforcement for effort was provided to maintain motivation, after practice trials and after each task.

Table 6.12.

Summary of Experimental Measures of Inhibition

Inhibition Domain	Response Modality	Task	Measurement
Response Inhibition	Motor	AdVIMI	RT, MT, Error rate
	Verbal	AdVIMI	RT, Error rate
Interference Control	Motor	AdFlanker	RT, Error rate
	Verbal	AdAC	CT, Error rate

Note: RT – Reaction Time; MT – Movement Time; CT – Completion Time

6.4.1. Ethical Approval

The study was approved by the University Research Ethics Committee at Oxford Brookes University (UREC number: 181186, see Appendix H for confirmation letter). Parents were supplied with participant information sheets and required to sign the appropriate consent forms prior to testing sessions (See Appendix I, J and K). Due to the young age of the children participating, they were asked to provide verbal assent following an explanation of the content of the sessions from the tester.

6.4.2. Testing Sessions

In addition to the measures outlined above, all children completed the full IDS-2 as part of the broader UK standardisation project. The complete battery is outlined in Appendix A. For the current studies, only the measures outlined above are reported. The tester was a qualified Occupational Therapist trained to administer all of the standardised assessments used. All measures were administered either according to manual instructions (for standardised tests) or the scripts provided in Appendix C and G (for experimental tasks).

Children were assessed individually over three sessions lasting just under two hours each; each session occurred on a different day. The MABC-2 Test session was completed either in a child's own home, school or at Oxford Brookes University depending on parental preference. Parents then decided if they wanted the next two sessions, which included the full IDS-2 test battery and experimental tests, administered at home or at Oxford Brookes University. Breaks were provided during each session and children were made aware that they could stop at any time. Children in the DCD group all completed the MABC-2 Test session first as it formed part of the diagnostic procedure, they then completed the next two sessions, which included the IDS-2 test battery and experimental tasks. Due to requirements for the broader IDS-2 standardisation project, MABC-2 testing in the TD group was counterbalanced. Therefore, half of the children in the TD group completed the MABC-2 Test in the first session and then completed the next two sessions which included the IDS-2 test battery and experimental tasks. The other half first completed the two sessions which included the IDS-2 test battery and experimental tasks, and then completed the MABC-2 Test in the third session. The interval between the IDS-2 1st and 2nd session was less than one month, and less than three and a half months elapsed between the completion of the MABC-2 Test and the first or last IDS-2 sessions. This ensured that developmental changes did not greatly influence the results in later testing sessions. Following enrolment, nobody requested to terminate the sessions early or withdraw from the research.

6.4.3. Scoring Summary

All standardised tasks were scored according to the instructions in the manuals. As mentioned previously, standardised scores were not available for the IDS-2 Psychomotor and Executive Function components so point scores were calculated according to manual instructions and used for analysis. All experimental measures of Inhibition were scored using a measure of error and time. The AdVIMI Motor component congruent and incongruent conditions were scored on measures of error rate, RT and MT, and the AdVIMI Verbal component congruent and incongruent conditions were scored on measures of error rate and RT. The scores from the incongruent conditions were the measures of Response Inhibition, as well as the difference in error rate and time between the congruent and incongruent conditions for the Motor and Verbal components. Further details on the scoring of the AdVIMI is provided in Appendix D. The AdFlanker was scored on measures of error rate and RT for the congruent and incongruent condition. The error rate and RT of the incongruent condition, as well as the difference between error rate and RT from the congruent to incongruent conditions were the measures of Interference control requiring a motor response. The AdAC was scored on error rate and completion time of the Incongruent condition, which were the measures of Interference Control requiring a verbal response.

6.5. Statistical Analysis

The data collected were analysed using the statistical software Jamovi version 0.9. The data were first tested for normality using the Shapiro-Wilk test. This calculated the level of significance (values above .05 are considered normally distributed, less than .05 indicate a deviation from normal distribution) (Field, 2013). Homogeneity of variance was also examined using Levene's test for equality of variance. Significance levels above .05 indicate equal variance (Field, 2013). If the data met the assumptions of normality and equal variance then parametric tests were conducted, otherwise non-parametric alternatives were used. The statistical analysis techniques used to meet the aims of Study One and Two are presented below. Effect sizes were reported for all analyses, cut-offs of 0.10 – < 0.30 for a small effect, 0.30 – < 0.50 for a medium effect, and ≥ .50 for a large effect were used (Cohen, 1988).

6.5.1. Study One

The aim of Study One was to examine the Executive Function and Inhibition specific skills of children with DCD and TD children using a broad range of measures. Therefore, group differences were examined across all the measures of Executive Function described in sections 6.3.2. and 6.3.3. For experimental tasks the incongruent condition was used for analysis as this was the condition which required Inhibition. Correlational analysis was also used to examine relationships between RT and error rate, and MT and error rate for each group on the experimental tasks. Group differences on the experimental measures were also considered in a subsample of six children from the DCD group with less severe motor difficulties (MABC-2 Total test scores 9^{th} – 16^{th} percentile) and six age and gender matched TD peers. This was to consider if the severity of motor difficulty potentially affected the results, and if so, if tasks with a motor and verbal response were affected differently.

Some additional analyses were also conducted to address the issue of potential confounding variables. Potential confounding variables were identified as the presence of a diagnosed co-occurring condition (e.g. ASC or ADHD), and the higher Hyperactivity and Inattention score found in the DCD group (see Table 6.5.). ASC and ADHD were identified as potential confounding variables because difficulties with Executive Function skills have been widely reported in children with ADHD and ASC (Craig et al., 2016) which could influence the results. Tests were carried out removing the children with co-occurring conditions to assess the extent to which these effected results. Removing children with co-occurring conditions was not found to substantially change the results found when all children were included in the analysis (i.e. no children were excluded). The full results of these analyses can be found in Appendix L.

The higher Inattention and Hyperactivity scores found in the DCD group were identified as a potential confounding variable because hyperactivity and inattention is widely reported to be associated with poorer skills in Executive Function (Silverstein et al., 2020). However, it is also important to note that the higher rate of hyperactivity and inattention in the DCD group has not occurred at random due to issues with sampling but appears instead to represent a characteristic common to children with DCD. Furthermore, questions on the hyperactivity and Inattention scale of the SDQ (e.g. constantly fidgeting or squirming', 'concentration wonders', 'doesn't think things through before acting') are similar to those on the Inhibit scale of the BRIEF-2 (e.g. 'is fidgety', 'talks at wrong time', 'is impulsive'). Therefore, it is possible that the SDQ hyperactivity and Inattention scale is also measuring aspects of Inhibition in everyday life. As such, Hyperactivity and Inattention scores have not been factored into the main analysis presented in chapter seven. However, when assumptions have been met, ANCOVA has been used to examine the main effect of group and main effect of 'hyperactivity' (measured by the hyperactivity and inattention scale of the SDQ). The results are reported in Appendix B, showing that this did not substantially effect the results. Previous studies investigating potential differences in Executive Function in children with DCD and TD peers have used hierarchical regressions (Bernardi et al., 2018, 2016; Leonard et al., 2015; Piek & Murray, 2007; Pratt et al., 2014). These studies did not use tightly matched groups and therefore hierarchical regressions were necessary to control for several confounding variables such as age, sex, IQ and social economic status. For Study One, due to the tight matching of the groups, T-tests and the non-parametric alternative Mann-Whitney-U tests were used to examine the differences between mean values on a range of measures of Inhibition and Executive Function.

Chi Squared analyses were also used to investigate some results in further detail, to examine the proportion of children in each group who fell within ‘average’ ‘below average’ and ‘above average’ levels on each measure. These Chi Squared analyses used estimated proportions based on the TD sample distributions for all measures, up to 1 SD from the TD mean was considered ‘average’, 1 SD below was ‘below average’ and 1 SD above was ‘above average’. 1 SD from the mean is often what is used in clinical practice to identify a difficulty in a domain of interest. Therefore, these Chi Squared analyses enable comparison to go beyond the group differences in the mean and examine whether any potential differences observed are also possibly of ‘clinical significance’.

6.5.2. Study Two

The aim of Study Two was to examine relationships between Inhibition (parent/carer and teacher reported, Response Inhibition and Interference control) and motor skills in children with a range of motor skills. To meet this aim bi-variate correlational analyses were used to examine relationships between the motor variables in the areas of overall motor skill, gross motor skills (including ball skills), fine motor, and drawing skills, and measures of Inhibition (parent/carer and teacher questionnaire, and Response Inhibition and Interference Control tasks). The incongruent condition of the experimental tasks were used as this was the condition which required Inhibition. Significant relationships were also examined in each group separately as these enabled the relationships to be examined outside of the influence of potential group differences and consider if relationships between those with DCD and the TD control group differed. Results were considered meaningful if: 1) a significant relationship was found across the groups, and Study One did not find a significant difference between the groups on that Inhibition measure, or 2) if a significant relationship was found across the groups and also in either the DCD or TD group separately. In addition to reporting whether correlations were statistically significant, effect sizes were also considered (0.10 – < 0.30 for a small effect, 0.30 – < 0.50 for a medium effect, and ≥. 50 for a large effect) (Cohen, 1988). Study Two was exploratory in nature because of the limited research which has examined relationships between Inhibition and motor skills. It took a systematic approach by considering relationships between each area of motor skills and Response Inhibition, Interference Control and parent/carer and teacher reported Inhibition. Correlational analyses were chosen as this is the most commonly used method for assessing the presence of statistically significant relationships (Field, 2013). Other analysis techniques such as regression analysis or structural equation modelling are available which can consider the impact of variables which could account for any relationship found. However, due to the exploratory nature of Study Two it was reasoned that correlational analysis was the most appropriate to first determine if there was a relationship between Inhibition and motor skills. Furthermore, correlational results do not imply causation. There are many different variables that could impact on relationships found and it was not possible to measure them all. Correlational analysis appropriately conveys the complexity of investigation in this area.

Previous research has differed in how relationships between Inhibition and motor skills have been examined. Due to the large number of possible comparisons the decision was made to first consider relationships across the full data set (n = 50). Relationships were then only examined in each group separately, if a statistically significant relationship was found across the entire group first.

Study One and Two align to the widely cited work of Althouse's, (2016) (Martin-Willet et al., 2020; Bingham et al., 2019) recommendations for multiple comparisons rather than using statistical corrections. These are 1) to clearly define the methodology used within the research 2) to report effect sizes, confidence intervals and p values, and 3) to then allow the reader to use their own judgment regarding the weight of the conclusions drawn from these comparisons. In the text, p values of less than .05 are reported as ‘statistically significant’. Further justification for this approach to multiple comparisons is provided in Appendix M.

7. Study One Results. Executive Function in Children with and without DCD with a focus on Inhibition

7.1. Introduction

The literature review presented in chapter four revealed that whilst children with DCD have been found to have difficulties with Inhibition, findings have not been consistent across the literature. Many studies did not describe how the full DCD diagnostic criteria were met, and few studies used tasks that required both verbal and motor responses to compare the effect of response modality on results. A large proportion of the research also did not state what aspect of Inhibition was under investigation and at times this led to inappropriate interpretations of results. Most research has included either a measure of error rate or a measure of time, when both together may provide more useful information. Only one study considered parent/carer perspectives, and this was in a sample of children too young for a DCD diagnosis, and no previous research has considered teacher perspectives. Previous research which has examined Inhibition only used tasks that aimed to isolate Inhibition from other components of Executive Function. This research did not consider the role of Inhibition when used alongside other components, i.e. how Executive Function is used in everyday tasks. The aim of Study One was therefore to examine the Executive Function skills of children with and without DCD, with a focus on Inhibition, using a comprehensive range of measures.

The results from Study One are presented in this chapter. First, the performance of children with DCD is compared against the performance of age and sex matched typically developing peers on each measure. Additional analyses have been conducted to investigate any differences observed by accounting for variables such as: potential differences between raters on questionnaires, the presence of co-occurring conditions and the severity of the movement difficulties of children with DCD. These analyses enable conclusions to be made regarding any observed differences in Executive Function and Inhibition specifically between those with DCD and the typically developing (TD) control group.

7.2. Data Analysis

The data analysis techniques that have been used were outlined and justified in the previous chapter on methodology (Section 6.5.1.). Results from the full analyses are provided in Appendix N, including test statistics, exact p values, and 95% confidence intervals. Results are presented in three sections, first experimental tasks which assessed Response Inhibition and Interference Control are considered, the incongruent conditions of these tasks are used as the measure of Inhibition. The standardised battery of Executive Function is then considered, followed by the results of the parent/carer and teacher questionnaires.

7.3. Experimental Tasks

7.3.1. Response Inhibition

7.3.1.1. Motor Response. Table 7.1. displays the mean and SD for each group on the AdVIMI Motor task, with levels of statistical significance and effect sizes for group differences also shown. Significant group differences were found for error rate and Movement Time (MT) for both the congruent and incongruent conditions. Children with DCD made more errors than their TD peers and took longer to move into position. Group differences in completion time (Reaction Time (RT) + MT) were also significant for the congruent ($U = 206$, $p = .040$) and incongruent ($t(48) = 2.92$, $p = .005$) condition. There were no significant group differences in RT for either condition.

As significant group differences were found for Error Rate and MT across both the congruent and incongruent conditions, a further analysis was conducted to assess whether the conditions affected each group in the same manner. Figure 7.1. shows the mean error rate for each condition separated by group and Figure 7.2. shows mean MT for each condition separated by group. Mann Whitney U tests were performed to investigate these differences. For Error Rate a significant group difference, representing a large effect ($d = .60$) was found in the increase in error between congruent and incongruent conditions ($U = 208$, $p = .043$), children with DCD had a larger increase across the conditions ($M = 7.80$, $SD = 6.83$) than the TD control group ($M = 4.52$, $SD = 3.55$). There was also a significant difference between the groups for the increase in MT between the congruent and incongruent conditions ($U = 204$, $p = .035$) representing a large effect size (d =

.66). Children with DCD had a larger increase in MT across the conditions (M = .31, SD = .17) compared to TD controls (M = .22, SD = .12).

The way in which children moved their hands from the mat was categorised and scored for each trial. Table 7.2. shows the mean number of times each type of hand movement was performed for each group for the incongruent condition and if there was a significant group difference in the type of movements performed. This was considered within the incongruent condition as this was the condition that required Inhibition. Further details on how these hand movements were categorised can be found in Appendix D. There was a significant group difference, representing a large effect size (d = .69), in the total number of times the movement categorised as 'G' (two hands moving off the mat simultaneously) was performed (U = 25, p = .021). Children with DCD performed this movement more frequently (n = 5) than their typically developing peers (n = 0). There were no other significant group differences in how children moved their hands from the mat to respond.

Table 7.1.

Mean (SD) AdVIMI Motor Scores for the DCD and TD groups

Measure	DCD (n = 25) Mean (SD)	TD (n = 25) Mean (SD)	p	Cohen's d
Congruent Error rate[1]	6.24 (2.13)	4.88 (3.26)	*	.49
Congruent RT[1] (Msec)	350 (120)	330 (110)		.17
Congruent MT[2] (Msec)	640 (110)	560 (90)	**	.73
Incongruent Error rate	14.00 (6.21)	9.40 (4.97)	**	.82
Incongruent RT (Msec)	470 (200)	430 (180)		.21
Incongruent MT[1] (Msec)	950 (190)	780 (170)	***	.96

Note: ***≤.001; ** ≤.01; *≤ .05
RT - mean trial RT; MT – mean trial MT
[1] Mann-Whitney U
[2] Significant difference also found for completion time

Figure 7.1.

AdVIMI Motor Error Rate for Congruent and Incongruent Conditions in the DCD and TD groups

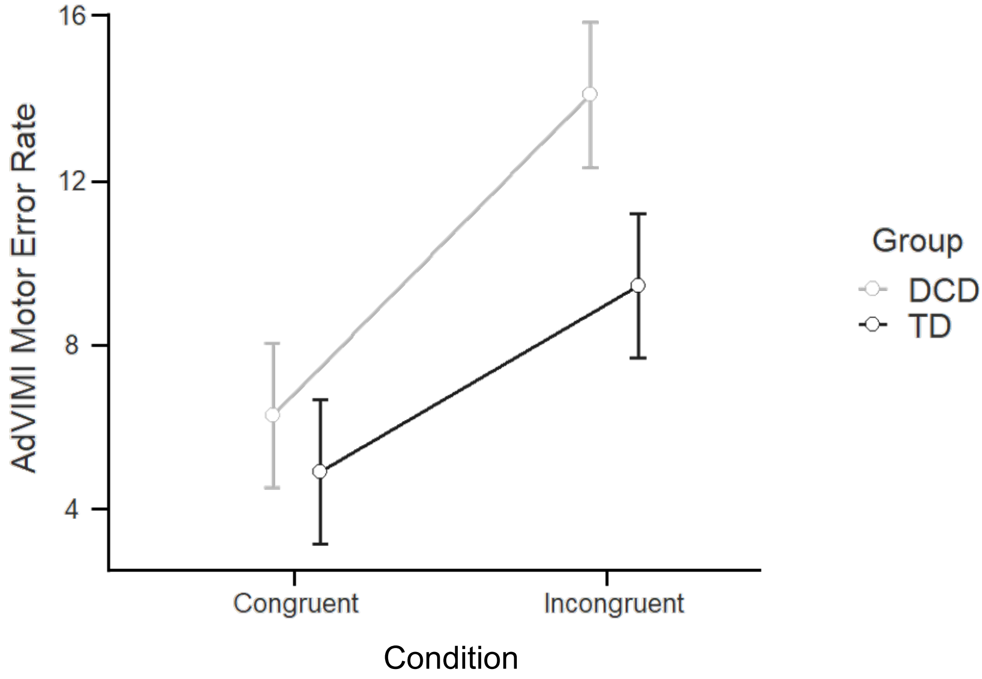


Figure 7.2.

AdVIMI Movement Time for Congruent and Incongruent Conditions in the DCD and TD groups

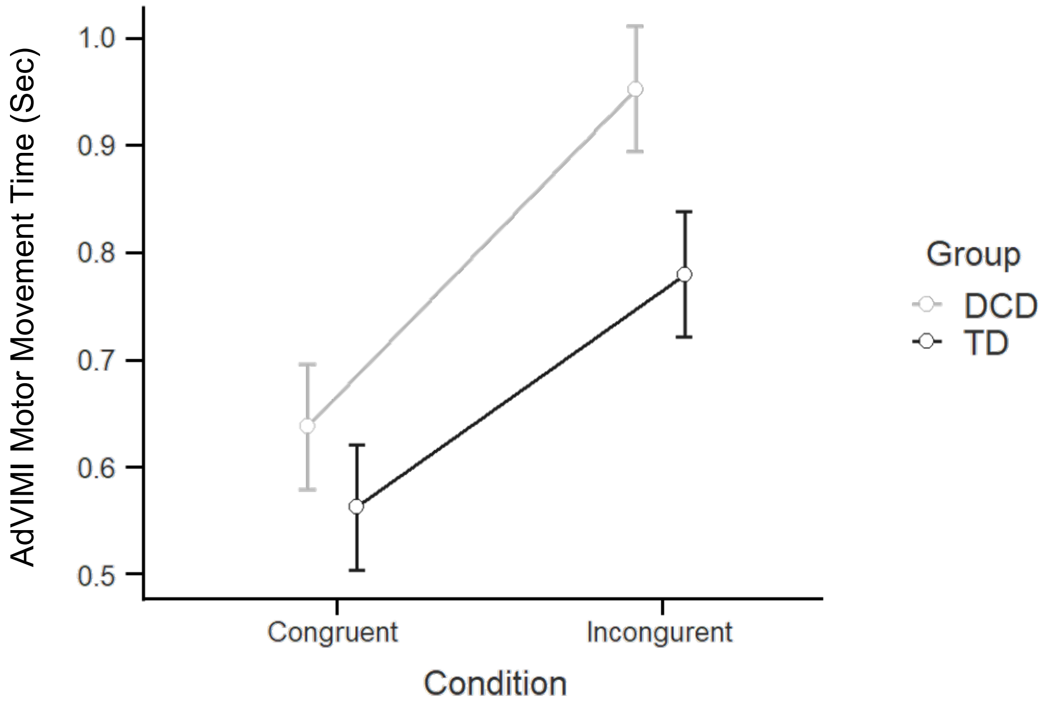


Table 7.2.

Mean (SD) Number of Each Movement Type in the AdVIMI Motor Incongruent Condition for the DCD and TD groups

Movement Code	Description	DCD (n=25) Mean	TD (n =25) Mean	p
A	Whole Hand	5.40	5.40	
B	Fingers Not in Unison	2.84	3.04	
C	Slide	4.84	4.92	
D	Fidgety	.720	.480	
E	Purposeful Arching	3.00	4.08	
F	Up, Down, Up	.520	.24	
G	Two Hands off Matt to Respond	.20	0	*
H	Hand in Fist/Difficult to Explain	.60	.24	
I	Hand Starting from Mid Air	1.80	1.60	

Note: *p ≤ .05; see Appendix D for a description of the categories

7.3.1.1.1. Speed Accuracy Trade Off. To examine relationships between speed of reactions and speed of movement to error rate, in the DCD and TD group, correlational analysis was performed between time scores (MT and RT) and error rate of the AdVIMI motor incongruent condition. In the TD group a moderate significant negative relationship was found between RT and error rate ($r = -.62$, $p < .001$) indicating that longer RTs were associated with a lower error rate. A significant moderate positive relationship was also found between MT and error rate ($r = .51$, $p = .009$) indicating that longer MTs were associated with higher error rates. No significant relationships were found for the DCD group between RT and error rate ($r = -.24$, $p = .235$) or MT and error rate ($r_s = .22$, $p = .296$).

7.3.1.1.2. Analysis of Subsample with Less Severe Motor Difficulties. Six children with DCD had less severe movement difficulties (MABC-2 Test 9th - 16th percentile). An analysis of this subsample compared with six age and sex matched TD peers is presented in Table 7.3 and shows no significant group differences.

Table 7.3

Mean (SD) AdVIMI Motor Scores for Subsample of Children with DCD with Less Severe Motor Difficulties and TD Matched Controls.

Measure	*DCD (n = 6)* *Mean (SD)*	*TD (n = 6)* *Mean (SD)*	*p*	*Cohen's d*
Incongruent Error rate	9.83 (6.40)	12.3 (5.01)	.468	.44
Incongruent RT (Msec)	572 (252)	370 (175)	.137	.93
Incongruent MT (Msec)	844 (157)	780 (250)	.602	.31

Note: RT - mean trial RT; MT – mean trial MT

7.3.1.2. Verbal Response. Table 7.4. displays the means and SD for each group on the AdVIMI verbal task with levels of statistical significance and effect sizes for group differences also shown. A significant difference, representing a medium effect size, was found for error rate for the incongruent condition. Children with DCD made more errors compared to their TD peers. There were no significant group differences in error rate for the congruent condition or for RT for either condition.

Table 7.4.

A Comparison of Mean (SD) AdVIMI Verbal scores for the DCD Group and TD groups

Measure	*DCD (n = 25)* *Mean (SD)*	*TD (n = 25)* *Mean (SD)*	*p*	*Cohen's d*
Congruent Error	1.28 (1.57)	.96 (1.06)		.24
Congruent RT (Msec)	730 (140)	660 (80)		.59
Incongruent Error rate	4.76 (8.54)	.20 (.50)	***	.75
Incongruent RT (Msec)	850 (230)	770 (160)		.43

Note: ***≤.001
RT – Mean trial RT

Further analysis was performed to examine whether the effect of condition was the same for each group. The data did not meet the assumption of Leven's test of homogeneity of variance required to investigate potential interaction effects using ANOVA. Therefore, Mann Whitney U tests were performed to investigate if the difference in error rate or RT from the congruent condition to incongruent condition significantly differed according to group. There was no significant difference found between the groups for increase in error rate (U = 306, p =.906), or RT (U = 266, p = .506) between condition

7.3.1.2.1. Speed Accuracy Trade Off. As above (section 7.3.1.1.1.), to examine relationships between speed and error rate in the DCD group and TD control group correlational analysis was performed between RT and error rate of the AdVIMI Verbal incongruent condition. No significant relationship between RT and error rate was found for the TD group (r_s = .02, p =936) or the DCD group (r_s = .14, p = .497).

7.3.1.2.2. Analysis of Subsample with Less Severe Motor Difficulties. As described above (section 7.3.1.1.2.), the analyses were repeated on a subsample of six children with less severe movement difficulties. A significant group difference was found on AdVIMI verbal error rate with a large effect size (U = 4.50, p = .025, d = 1.62). This shows that children with DCD made more errors

(M = 2.00, SD = 1.55) than age and sex matched TD peers (M = .17, SD = .14). No group difference was found for RT (t(10) = 1.15, p = .275).

7.3.1.3. Effect of Response Modality. Results from the Response Inhibition tasks (AdVIMI motor and verbal tasks incongruent conditions) were then analysed together to examine if response modality effected performance. There were significant effects of response modality for both error rate (U = 246, p <.001) (verbal M = 3.36, SD = 6.32; motor M = 11.70, SD = 6.04) and RT (t(98)) = 9.25, p <.001) (verbal M = .76, SD = .20; motor M = .45, SD = .19). Error rates were higher and RT faster for the motor condition. Figures 7.3. and 7.4. display group performance on the Response Inhibition tasks by response modality for error and RT respectively. A two-way analysis of variance did not find a significant group by modality interaction effect for Response Inhibition RT (F(1, 96) = .316, p .576). This suggests that the effect of response modality did not differ between the groups. A Mann-Whitney U test was performed to investigate if the increase in error rate between a verbal response modality and a motor response modality differed for those with DCD and TD peers. Whilst the increase in error rate was higher for the DCD group (M = 9.28, SD = 10.8) compared to the TD group (M = 7.44, SD = 5.44), this difference was not significant (u = 224, p =.087).

Figure 7.3.

Group-by- Response Modality AdVIMI Inhibition Reaction Time Incongruent Condition

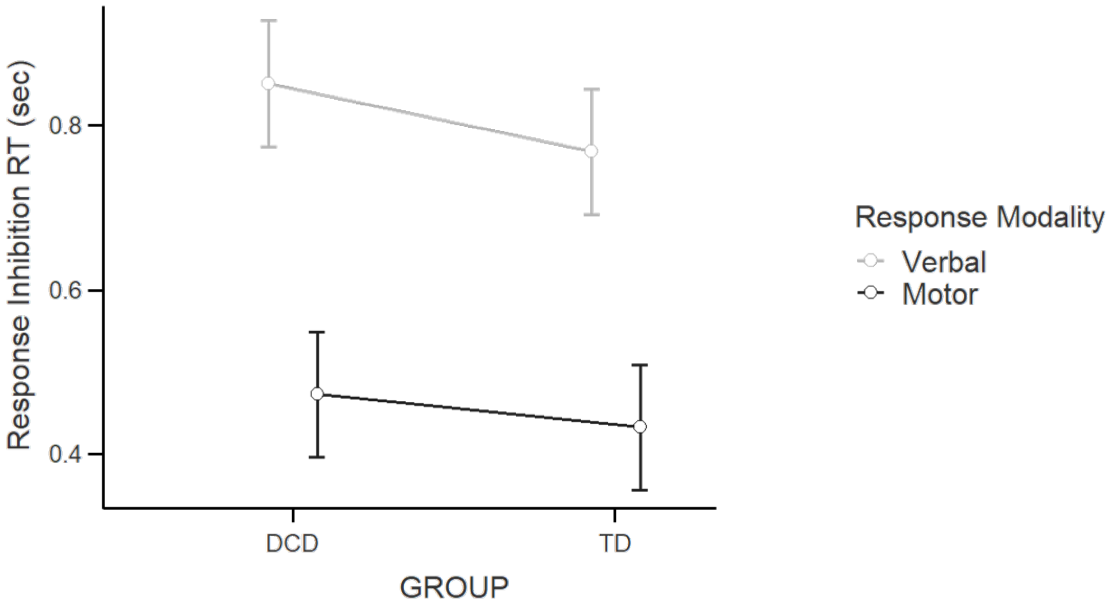
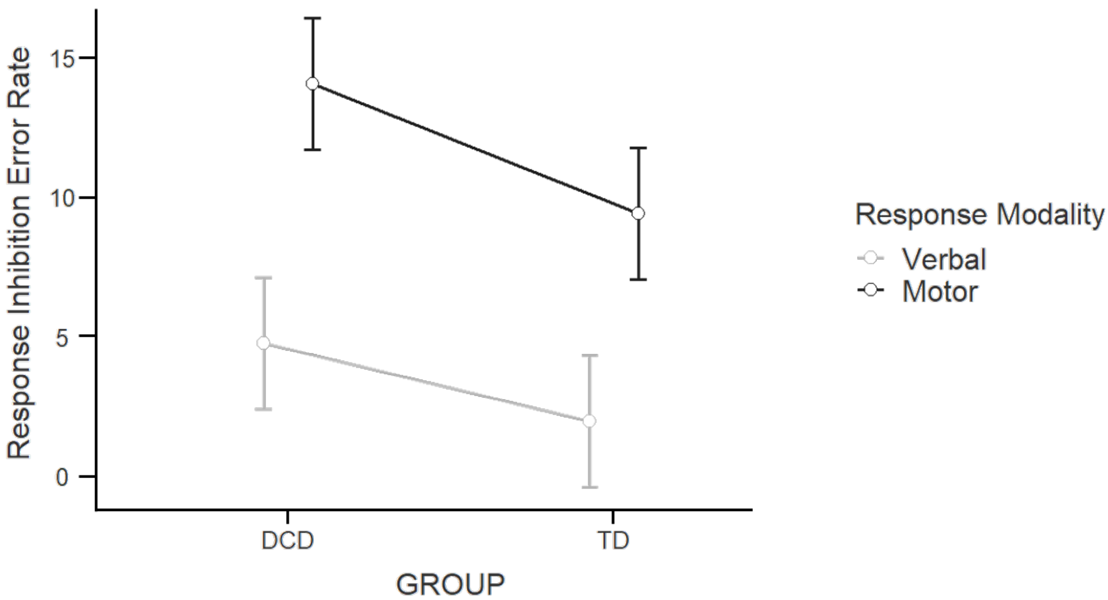


Figure 7.4.

Group-by-Response Modality AdVIMI Error Rate Incongruent Condition



7.3.2. Interference Control

7.3.2.1. Motor Response. Table 7.5. outlines the means and SD for each group on the AdFlanker task, together with results of Mann-Whitney U tests to investigate group differences. Significant group differences representing large effects were found for RT for both the congruent and incongruent conditions, with children with DCD reacting more slowly than their TD peers in both conditions. There were no significant group differences in error rate for either condition. Mean error rate scores for both groups in each condition fell below one indicating a low rate for both groups.

To further investigate the significant group difference for AdFlanker RT for the congruent and incongruent conditions, the effect of condition was considered across groups using a Mann Whitney U test. Figure 7.5. shows the mean RT for a trial for each condition separated by group. No significant difference between the groups was found (U = 260, p = .316).

Table 7.5.

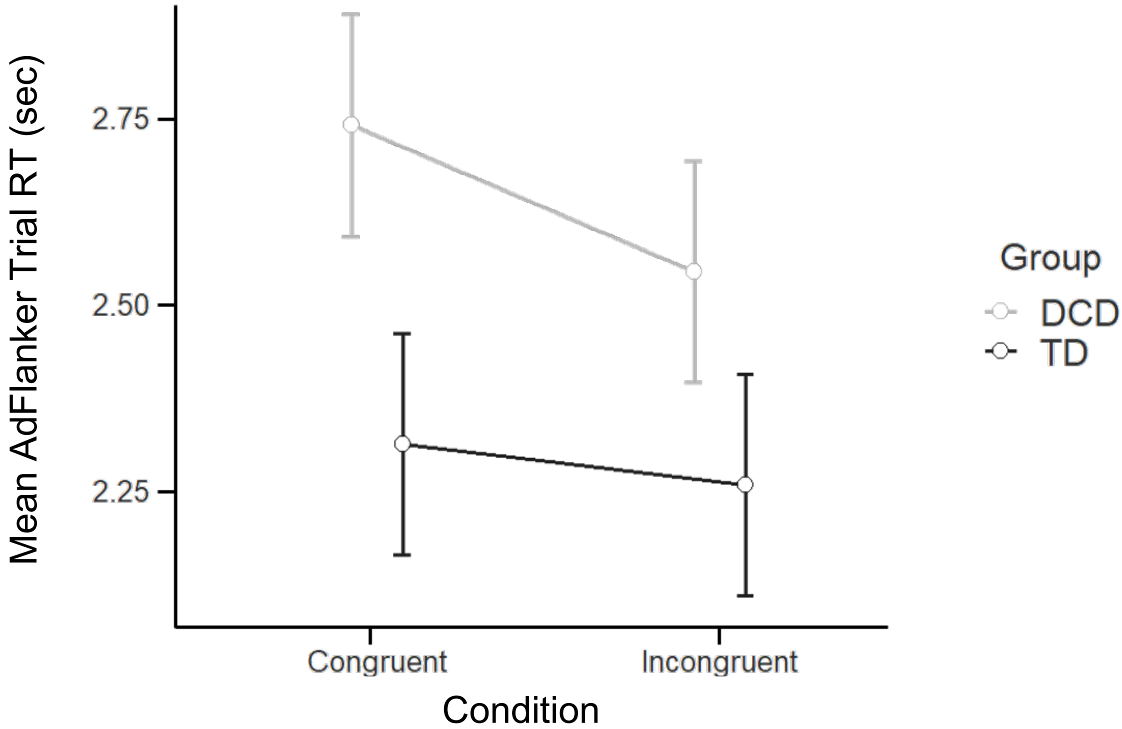
A Comparison of mean (SD) AdFlanker Scores for the DCD and TD groups

Measure	*DCD (n = 25)* *Mean (SD)*	*TD (n = 25)* *Mean (SD)*	*p*	*Cohen's d*
AdFlanker Congruent Error rate	.76 (2.01)	.12 (.33)		.45
AdFlanker Congruent RT (Sec)	2.74 (.54)	2.31 (.15)	**	1.04
AdFlanker Incongruent Error rate	.56 (1.04)	.20 (.05)		.44
AdFlanker RT Incongruent (Sec)	2.54 (.46)	2.26 (.18)	*	.82

Note *** ≤.001; ** ≤.01; *≤ .05
RT – mean trial RT

Figure 7.5.

AdFlanker Mean Trial Reaction Time for Congruent and Incongruent Conditions for the DCD and TD groups



7.3.2.1.1. Speed Accuracy Trade Off. As above (section 7.3.1.1.1) to examine relationships between speed and error rate in the DCD and TD groups correlational analysis was performed between RT and error rate of the AdFlanker incongruent condition. No significant relationship between RT and error rate was found for the TD (r_s = -.26, p = .208) or the DCD group (r_s = .01, p = .975).

7.3.2.1.2. Analysis of Subsample with Less Severe Motor Difficulties. As described above (section 7.3.1.1.2), the analyses were repeated on a subsample of six children with less severe movement difficulties and age and sex matched TD peers. No significant differences were found between those with DCD and TD peers on error rate (t(10) = .88, p =.401, d = .51) DCD (M = 5, SD = .84) TD (M = .167, SD = .41) or RT (U = 15, p = .699, d =.167) DCD (M = 2.37, SD = .32) TD (M = 2.26, SD = .19).

7.3.2.2. Verbal Response. Table 7.6. displays the means and SD for each group on the AdAC task for completion time for the congruent and incongruent condition and error rate for the incongruent condition. Table 7.6. also shows the statistical significance and effect sizes for group differences. A significant group difference, representing a large effect size, was found for completion time of the incongruent condition. Children with DCD performed more slowly than their TD peers. There were no significant group differences for completion time for the congruent condition or for error rate for the incongruent condition, data were not collected on error rate for the congruent condition. Mean error rates for both groups were low (DCD M = 1.20; TD M = .24) indicating neither group made many errors.

The effect of condition for the AdAC was considered across groups with a Mann-Whitney U test. Figure 7.6. shows completion time for each condition separated by group. This showed a significant group difference, representing a large effect size (d = .75) (U = 160, p = .005) with children with DCD having a larger increase in time between the conditions than the TD group.

Table 7.6.

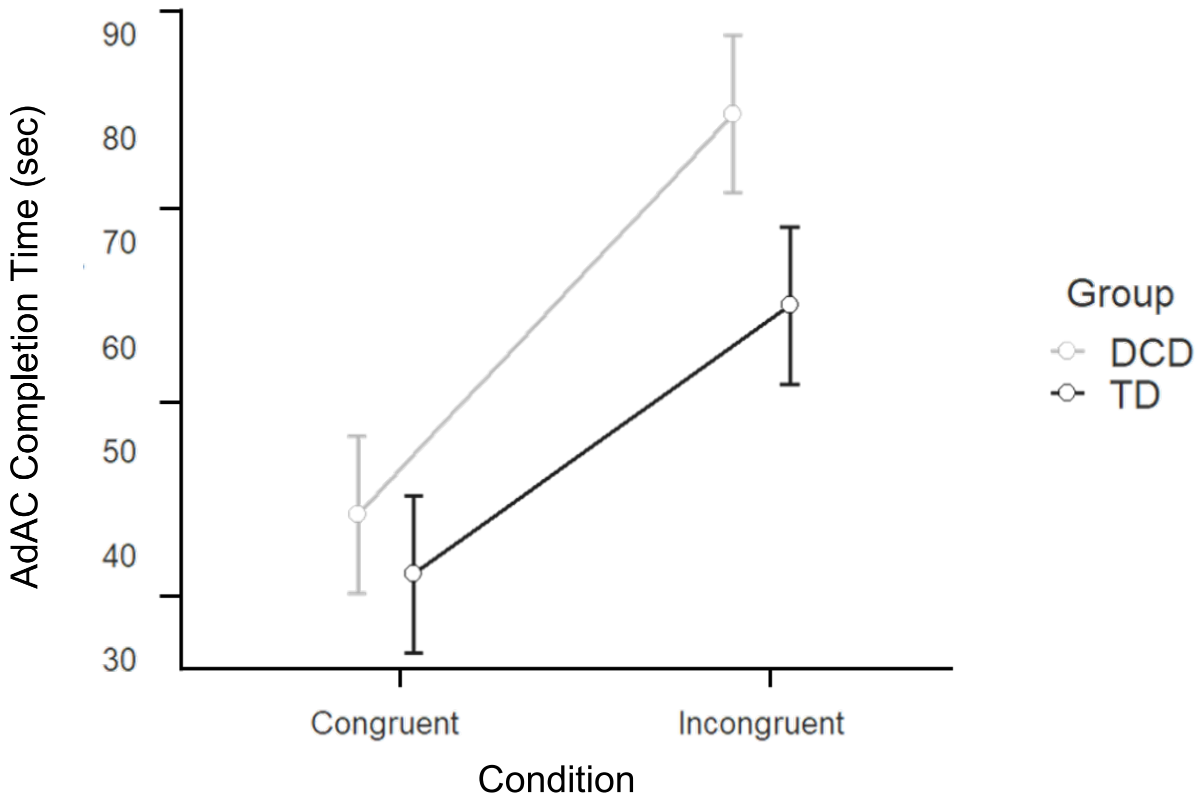
Mean (SD) AdAC Scores for the DCD and TD groups

Measure	*DCD (n = 25)* *Mean (SD)*	*TD (n = 25)* *Mean (SD)*	*p*	*Cohen's d*
AdAC Congruent Completion Time	43.80 (13.60)	38.10 (10.20)		.51
Ad AC Incongruent Error rate	1.2 (2.23)	.24 (.66)		.56
AdAC Incongruent Completion Time (sec)	82.3 (26.1)	63.8 (21.7)	**	.76

Note: **≤.01

Figure 7.6.

AdAC Completion Time for Congruent and Incongruent Conditions for the DCD and TD groups



7.3.2.2.1. Speed Accuracy Trade Off. As above (section 7.3.1.1.1.), to examine relationships between speed and error rate in the DCD and TD groups correlation analysis was performed between completion time and error rate on the AdAC incongruent condition. In the DCD group a moderate significant positive relationship was found between completion time and error rate (r_s = .49, p = .012) indicating that longer completion times were associated with a higher error rate. No significant relationships between completion time and error rate were found for the TD group (r_s = - .30, p = .142).

***7.3.2.2.2. Analysis of Subsample with Less Severe Motor Difficulties*.** As described above (section 7.3.1.1.2.), the analyses were repeated on a subsample of six children with less severe movement difficulties. No significant differences were found between those with DCD and TD groups on error rate (U = 17.50, p = 1.00, d = .028) DCD (M =.68, SD = 1.63) TD (M = .50, SD = 1.22) or Completion Time (U = 13, p = .485, d = 2.79) DCD (M = 74.7 SD = 27.10) TD (M = 69.00, SD = 34.60).

Table 7.7.

Summary of Results Investigating Differences between DCD and TD groups on the Experimental Tasks

Measure		**RT**		**Error**		**CT**		**MT**
Modality		Verbal	Motor	Verbal	Motor	Verbal	Motor	Motor
Response Inhibition	Congruent				*	n/a	*	**
	Incongruent			***	**	n/a	**	***
Interference Control	Congruent	n/a	**	n/a			n/a	n/a
	Incongruent	n/a	*			**	n/a	n/a

Note: ***≤ .001; **≤.01, *≤.05
Black filled – no significant difference found
N/A – not applicable because it wasn't measured

7.3.3. Summary for Experimental Tasks

Table 7.7. displays an overview of the results from the experimental tasks. Children with DCD were found to have poorer performance on experimental measures of Response Inhibition and Interference Control which required both a motor and verbal response when compared to TD peers. However, differences between the groups were not found across all measures used.

7.4. Intelligence and Developmental Scales Assessment 2nd Edition Executive Function Component (IDS-2-EF)

Table 7.8. displays the means and SD for each group on the Executive Function component of the standardised battery, the IDS-2 as well as the statistical significance levels and effect sizes for group comparisons. At the time of data collection and analysis standard scores were not available so data analysis is based on point scores.

All mean scores were poorer for the DCD group, however, significant group differences were found for only two of the IDS-2-EF measures. These were the Animal Colours task (U = 163, p .004) which represents a large effect (d = .76) and Divided Attention - Animals Listed task (t(28) = 2.88, p = .006) which represents a large effect (d = .81). No other significant differences were found between the groups on the IDS-2-EF tasks.

Table 7.8.

Mean (SD) IDS-2-EF scores for the DCD and TD groups

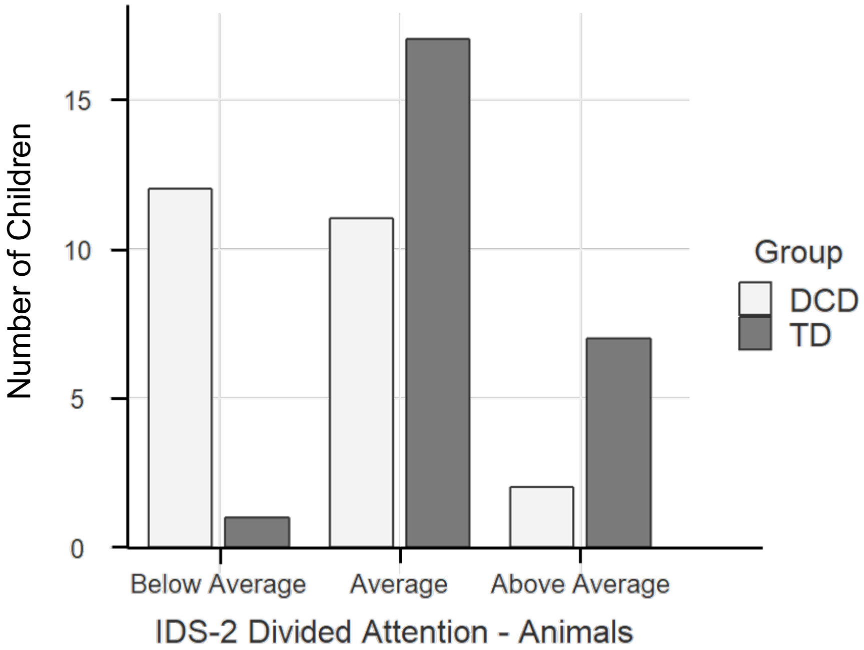
Measure	*DCD (n = 25)* *Mean (SD)*	*TD (n = 25)* *Mean (SD)*	*p*	*Cohen's d*
Listing Words No. words listed	39.90 (15.20)	45.3 (12.10)		.39
Divided Attention – Animals Listed	13.80 (6.05)	19.00 (6.63)	**	.81
Divided Attention – Parrots crossed out	19.50 (8.27)	21.30 (9.49)		.21
Animal Colours Time[1]	58.70 (20.50)	44.00 (18.1)	**	.76
Drawing Routes Time	23.50 (8.21)	21.90 (8.35)		.19
Drawing Routes Quality	17.00 (4.95)	19.50 (5.97)		.46

Note: ** ≤.01
[1]Mann-Whitney U
Units: Point scores

To consider the potential clinical significance of these results an 'average' range was calculated using the TD sample mean +/- one SD. This enabled the proportion of 'average', 'below average' and 'above average' results to be compared across the tasks. Figure 7.7. shows the proportion of children in each group who listed an average, more than average or less than average number of animals for the Divided Attention – Listing Animals task. A Chi Squared test of independence, performed using estimated proportions based on the TD sample, revealed a significant effect of group ($\chi^2 = 25.6$, $p < .001$). A higher proportion of children with DCD listed fewer animals and a lower proportion of children with DCD listed an average or above average number of animals compared to the TD group. No other IDS-2-EF task showed significant group differences in the distribution of scores.

Figure 7.7.

Distribution of Scores for the DCD and TD groups for the Divided Attention - Listing Animals Tasks



Note: Less: Number of words listed less than 1 SD from TD mean

Average: Number of words listed within 1 SD of TD mean

More: Number of words listed More than 1 SD from TD mean

7.4.1. Summary for IDS-2-EF

Children with DCD were found to have poorer mean scores than TD children on all measures of the IDS-2-EF. However, significantly poorer mean scores were found for only two measures, the Animal Colours task and the Divided attention Animal Colours task.

7.5. Behavioural Rating Inventory of Executive Function 2nd Edition (BRIEF-2) Questionnaires

7.5.1. Parent/Carer Questionnaire

Table 7.9. displays the means and SD for each group on the BRIEF-2 parent/carer Questionnaire, with higher scores indicating poorer performance. Table 7.9. also displays levels of statistical significance and effect sizes for group differences. Children with DCD had poorer skills across all areas of Executive Function assessed by the questionnaire. Effect sizes are all large.

As reported in section 6.3.2.2. BRIEF-2 scores can be categorised according to the US standardisation. For the Global Executive Composite score, in the DCD group, four children had scores in the 'typical' range (less than 60), six had scores in the 'mildly elevated' range (60-64), six had scores in the 'potentially clinically elevated' range (65-69) and nine had scores in the 'clinically elevated' range (70+). In the TD group 22 children had scores in the 'typical' range, one had a score in the 'mildly elevated' range, one had a score in the 'potentially elevated' range, and one had a score in the 'clinically elevated' range. For the Inhibit scale thirteen children with DCD had scores in the 'typical' range, eight had scores in the 'mildly elevated' range, three had scores in the 'potentially elevated' range, and one had a score in the 'clinically elevated' range. In the TD group 22 children had scores in the 'typical' range, one had a score in the 'mildly elevated' range, two had scores in the 'potentially clinically' elevated range and none had a score in the 'clinically elevated' range. In summary 60% (15/25) of the DCD group had at least potentially clinically elevated GEC scores (compared to 8% of the TD group) and 16% (4/25) had at least potentially clinically elevated Inhibit scores (compared to 8% of the TD group).

Table 7.9.

Mean BRIEF-2 Parent/Carer Questionnaire T scores (SD) for the DCD and TD groups

Measure	*DCD (n = 25) Mean (SD)*	*TD (n = 25) Mean (SD)*	*p*	*Cohen's d*
Inhibit	*58.00 (8.35)*	*47.70 (8.99)*	***	*1.19*
Self Monitor	*56.70 (11.00)*	*47.3 (8.49)*	**	*.95*
Behavioural Regulation Index (BRI)[1]	*57.90 (8.68)*	*47.6 (9.08)*	***	*1.16*
Shift [1]	*61.20 (13.10)*	*50.10 (10.10)*	**	*.95*
Emotional Control	*58.50 (10.90)*	*51.70 (11.10)*	*	*.62*
Emotional Regulation Index (ERI)	*60.40 (11.10)*	*51.00 (9.11)*	**	*.92*
Initiate	*61.50 (8.72)*	*47.20 (8.51)*	***	*1.66*
Working Memory	*64.50 (9.40)*	*48.80 (9.11)*	***	*1.69*
Plan	*63.40 (7.96)*	*48.70 (8.03)*	***	*1.84*
Task Monitor	*64.90 (6.75)*	*46.40 (7.23)*	***	*2.65*
Organisation of materials	*64.20 (9.13)*	*50.30 (8.14)*	***	*1.60*
Cognitive regulation Index (CRI)	*65.40 (6.75)*	*48.10 (7.84)*	***	*2.37*
Global Executive Composite (GEC)	*66.50 (8.33)*	*49.50 (8.99)*	***	*1.96*

Note *** ≤.001; ** ≤.01; *≤ .05
[1] Mann-Whitney U test

7.5.2. Teacher Questionnaire

Table 7.10. displays the sample characteristics of the 16 Children with DCD and 13 TD children for whom teacher BRIEF-2 questionnaires were completed and returned. There were no significant group differences in age (t(27) = 1.12, p =.27) or sex. 15 children in the DCD group had no co-occurring conditions and one child in the DCD group had an additional dual diagnosis of ADHD and ASC.

For the Global Executive Composite score, in the DCD group seven children had scores in the 'typical' range, three had scores in the 'mildly elevated' range, five had scores in the 'potentially clinically elevated' range and one had a score in the 'clinically elevated' range. In the TD group eleven children had scores in the 'typical' range, one had a score in the 'mildly elevated' range, and one had a score in the 'potentially clinically elevated' range. For the Inhibit scale ten children with

DCD had scores in the ‘typical’ range, three had scores in the ‘mildly elevated’ range and three had scores in the ‘potentially clinically elevated’ range, no child had a score in the ‘clinically elevated’ range. In the TD group ten children had scores in the ‘typical’ range, none in the ‘mildly elevated’ range, two in the ‘potentially clinically elevated’ range and one child had a score in the ‘clinically elevated’ range. In summary 37.5% (6/16) of the DCD group had at least potentially clinically elevated GEC scores (compared to 7.7% of the TD group). The proportions of children with at least potentially clinically elevated Inhibit scores were very similar across the DCD and TD groups (19% and 23% respectively).

Table 7.10.

Sample Characteristics for the DCD and TD groups for Teacher BRIEF-2

	DCD (n = 16)	TD (n = 13)
Sex		
Male	15	12
Female	1	1
Age Years, Months (range)	8yrs 4 m (6yrs 2m – 10yrs 11m)	8yrs 9 m (7yrs 1m - 10yrs 9m)
Co-occurring conditions	1	-

Table 7.11. displays the means and SD for each group on the BRIEF-2 teacher questionnaire, higher scores indicate poorer performance. Table 7.11. also displays the statistical significance level, and effect sizes of statistical comparisons between the groups. Results show that there were significant group differences with a large effect size for the Shift, Initiate, Working Memory, Plan, Task Monitor and Organisation of Material scales, the Cognitive Regulation Index and the Global Executive Function Composite. This indicates that children in the DCD group were rated more poorly across these areas. No Significant group differences were found for the Inhibit, Self-Monitor or Emotional Control Scales or the Behaviour Regulation or Emotional Regulation Indexes.

Table 7.11.

Mean (SD) BRIEF-2 Teacher Questionnaire T scores for the DCD and TD groups

Measure	*DCD (n = 16) Mean (SD)*	*TD (n = 13) Mean (SD)*	*p*	*Cohen's d*
Inhibit[1]	*54.30 (9.64)*	*49.40 (13.87)*		*.42*
Self Monitor	*54.60 (9.71)*	*49.00 (11.20)*		*.54*
Behavioural Regulation Index (BRI)	*55.30 (10.00)*	*48.06 (12.00)*		*.61*
Shift	*59.60 (10.30)*	*50.70 (8.31)*	*	*.94*
Emotional Control[1]	*56.10 (13.30)*	*53.80 (13.50)*		*.17*
Emotional Regulation Index (ERI)[1]	*58.00 (11.87)*	*51.50 (9.54)*		*.59*
Initiate[1]	*56.30 (9.13)*	*48.50 (10.70)*	*	*.79*
Working Memory[1]	*61.30 (8.15)*	*49.40 (12.60)*	**	*1.14*
Plan	*57.00 (7.75)*	*47.60 (8.48)*	**	*1.16*
Task Monitor	*61.40 (8.29)*	*46.20 (8.99)*	***	*1.76*
Organisation of materials[1]	*57.30 (11.70)*	*46.40 (7.65)*	**	*1.08*
Cognitive regulation Index (CRI)[1]	*60.90 (7.56)*	*47.20 (9.16)*	***	*1.65*
Global Executive Composite (GEC)	*60.50 (7.97)*	*48.20 (8.98)*	***	*1.96*

Note *** ≤.001; ** ≤.01; *≤ .05
[1] Mann-Whitney U test

Further analyses are described in Appendix O investigating if there was systematic variance between responses by the parent/carer and the teacher on the two forms of the BRIEF-2. Results indicated that parents/carers and teachers did not significantly differ in their rating of the components on the BRIEF-2 form or in their rating of each group.

7.5.3. Summary for BRIEF-2

Significant group differences were found on all scales, indexes and the Global Executive Composite for the parent/carer BRIEF-2. On the teacher BRIEF-2 questionnaire significant group differences were found for Shift, Initiate, Working Memory, Plan, Task Monitor and Organisation of Material Scales, the Cognitive Regulation Index and the Global Executive Composite but no significant differences were found for the Inhibit, Self Monitor or Emotional Control scales or the Behavioural Regulation Index or Emotional Regulation Index.

7.6. Potential Confounding Variables

7.6.1. Diagnosed Co-occurring Conditions

The analyses of group differences reported above were repeated, after removing the eight children with DCD who had co-occurring conditions (and their eight TD controls). The BRIEF-2 teacher questionnaire was not able to be included in this additional analysis as the data for this was from a smaller sample in which participants were not matched. The results of these analyses are reported in full in Appendix L. These analyses were performed to assess if the results in this chapter could be explained by the inclusion of children with co-occurring conditions into the DCD group.

Significant differences between the groups were found to remain on the BRIEF-2 parent Inhibit scale ($t(34) = 2.36$, $p = .024$) and Global Executive Composite ($t(34) = 4.82$, $p \leq .001$), indicating that children with DCD were reported to have poorer Inhibition and overall Executive Function performance in everyday life. Significant differences were also found to remain on the IDS-2-EF Divided Attention – listing words task ($t(34) = 2.77$, $p \leq .001$), and IDS-2 Animal Colours task ($U = 80.50$, $p = .10$) indicating that children with DCD had poorer performance on these standardised measures. In the AdVIMI motor task, the Response Inhibition experimental task which required a motor response, significant differences remained between the groups for error rate ($U = 84$, $p = .14$) for the incongruent condition. This indicates that children with DCD without co-occurring conditions made more errors in this task compared to TD peers. Children with DCD were also found to make more errors on the incongruent condition of the AdVIMI verbal task, the Response Inhibition task which required a verbal component, ($U = 56$, $p \leq .001$). For the AdAC Interference Control task, which required a verbal response, children were found to have longer completion times in the incongruent condition ($U = 82$, $p =.012$). No significant difference remained for RT in the incongruent condition of the AdFlanker, the Interference control task which required a motor response, ($U = 121$, $p =.203$) when children with co-occurring conditions were excluded.

These additional analysis show that the results in this chapter were not considerably altered when children with co-occurring conditions were removed from the analyses. The results for the AdFlanker RT incongruent condition were the only results which were central to the research aim that were statistically significant when children with co-occurring conditions were included and no longer statistically significant when they were excluded. However, when the AdFlanker RT results were considered in the full sample significant group differences were found for both the congruent and incongruent conditions. Furthermore, the effect of condition on RT was not found to significantly differ between those with and without DCD. This suggests that the slower RT of the DCD group, when children with co-occurring conditions were included, may not be related to the Interference control demand of the task. Therefore, the lack of significant difference in AdFlanker RT when children with co-occurring conditions were removed does not considerably alter the results of Study One. No other results which were central to the research considerably altered when removing children with co-occurring conditions from the analysis.

7.6.2. Hyperactivity and Inattention

The specific issue of hyperactivity and inattention was addressed with some additional analyses using the Hyperactivity and Inattention scale of the Strengths and Difficulties questionnaire in analyses of co-variance. Appendix B provides results of these ANCOVAs, where data met the assumptions. In the BRIEF-2 parent/carer questionnaire the Shift scale and Behaviour Regulation Index did not meet the assumptions but all other scales, indexes and the Global Executive Composite score did meet the assumptions.

Hyperactivity and inattention were found to be a significant predictor of parent/carer reported Executive Function skills in all scales and indexes assessed excluding the organisation of materials scale, emotional control scale, and the Emotional Regulation Index. When accounting for the impact of hyperactivity and inattention, group differences previously found in the Inhibit, Self-Monitor and Emotional Control scales as well as the Emotional Regulation Index were no longer significant. The group differences on all other scales, indexes and the Global Executive Composite score remained significant.

In the BRIEF-2 teacher questionnaire the Self-Monitor, Shift, Plan, and Task Monitor scales, as well as the Behavioural Regulation Index, and Global Executive Composite score met the assumptions for ANCOVA. When controlling for hyperactivity and inattention on the Plan scale and the Global Executive Composite score group differences were no longer significant. Children with DCD were found to still have a significantly poorer score on the Task monitor scale ($F(1, 26) = 9.88$, $p <.004$, n^2p 0.28) and hyperactivity and inattention was not found to significantly affect performance on this scale $F(1, 26) =.19 = .668$, n^2p .01).

It was possible to use ANCOVA with all the IDS-2-EF tasks excluding the Animal Colours. Whilst previously children with DCD were found to list significantly fewer words than TD peers in the Divided Attention – Listing Animals task, this was no longer significant when controlling for hyperactivity and inattention. Hyperactivity and inattention alone were also not found to be a significant predictor of the number of words listed in the Divided Attention – Listing Animals task.

From the experimental tasks, the AdVIMI task, which required a motor response, was the only one to meet the assumptions of ANCOVA. Previously children with DCD were found to make significantly more errors than TD peers, however, this was no longer significant when controlling for hyperactivity and inattention. Hyperactivity and inattention in isolation were also not found to be a significant predictor of error rate on the AdVIMI which required a motor response. Previously children with DCD were also found to have longer MT than those without, this was found to remain significant and hyperactivity and inattention were also found to be a significant predictor of MT.

7.7. Performance Profiles Across all Measures of Executive Function

Performance across the range of above measures was also examined. Figure 7.8. is a heat map showing the performance of each child on every measure of Executive Function. Using the TD group mean for each measure of Executive Function, each group (DCD and TD) is organised from least number of scores in the ‘below average range’ to highest number of scores that fell into the ‘below average range’ (excluding Teacher BRIEF-2 scores as these were not available for every child.) Whilst every child had a least one score that fell 1 SD below the mean, the DCD group had a significantly greater proportion overall ($M = 13.96$) compared to the TD group ($M = 4.16$) ($t(48)) = 7.84$, $p \leq .001$); this represents a large effect (d = 2.17). The TD group had a greater proportion of average scores (M = 21.44) compared to the DCD group (M = 13.76) (t(48) = 6.48, p < .001), representing a large effect (d = .83) and the TD group had a greater proportion of scores that fell 1 SD above the mean (M = 3.74) compared to the DCD group (M = 1.80) (U = 103, p = .032), representing a large effect (d = 1.83).

Table 7.12. displays the proportion of children in each group who had at least 25% or more of their scores fall into the 'below average range'. This analysis excludes the Teacher BRIEF-2 questionnaire as not all children had data available from this measure. 92% of children (23/25) with DCD had at least a quarter of their Executive Function scores fall into the 'below average' range compared to 16% of TD children (4/25). 56% of children (14/25) in the DCD group had over half of their Executive Function scores fall into the 'below average' range. No children in the TD group had over half of their Executive Function scores fall into the 'below average' range.

Table 7.12.

The Frequency of Poor Performance across the Range of Executive Function Measures[1] for DCD and TD groups

% of Executive Function Scores in the Below Average Range	Number of Children whose Scores fall into each Category	
	DCD (n =25)	*TD (n =25)*
0 – 24%	2	21
25 – 50%	9	4
51 – 68%	10	0
69 – 100%	4	0

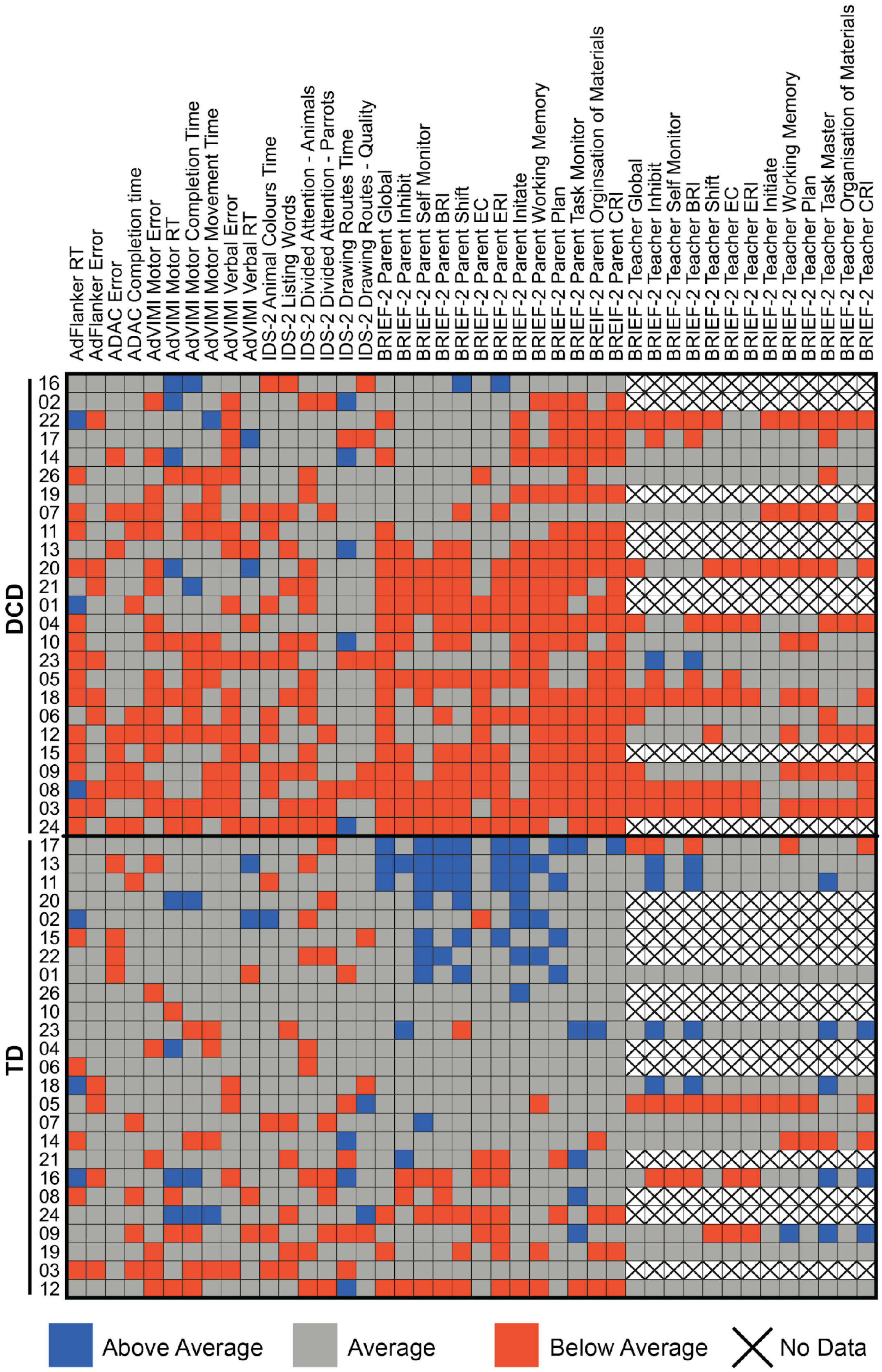
Note: Below average = 1 SD below the TD mean

[1] Excludes score from the teacher BRIEF-2

Figure 7.8.

Heat Map of Individual Performance Across All Measures of Executive Function

(n = 50) (25 DCD; 25 TD)



7.8. Summary

This chapter has shown the results of group analyses for children with DCD and age and sex matched TD peers across a range of measures of Executive Function. Inhibition (Response Inhibition and Interference Control) was systematically investigated in isolation from the other components of Executive Function using highly controlled experimental tasks. In the motor Response Inhibition task (AdVIMI Motor) children with DCD made significantly more errors and had significantly longer MT compared to the TD control group, but there was no difference in RT. In the verbal Response Inhibition task (AdVIMI Verbal) children with DCD made significantly more errors than the TD group, although there was no difference in RT. In the motor Interference Control task (AdFlanker) children with DCD had significantly slower RT, but there was no group difference in Error Rate. In the verbal Interference Control task (AdAC) children with DCD took significantly longer to complete the task, but there was no group difference in error rate. Results from the experimental tasks were considered in a sample of six children with DCD with less severe motor difficulties (MABC-2 Test total 9th -16th percentile) and age and sex matched TD peers. A significant difference was found to remain between the groups on error rate in the AdVIMI verbal task with children with DCD making more errors than TD peers. No other group differences on experimental measures were found to remain statistically significant when examined in this subsample.

In a standardised battery of Executive Function (IDS-2-EF) children with DCD had significantly poorer performance on two out of six of the measures. The IDS-2-EF tasks assess components of Executive Function working simultaneously, however, each task also has a primary Executive Function which is assessed more than others. The tasks that demonstrated significant group differences had a focus on Inhibition and Mental Flexibility. Results were then analysed for the parent/carer and teacher questionnaires which provide an understanding of Executive Function in everyday life. Children with DCD were found to have significantly poorer performance compared to their TD peers on all scales, indexes and the Global Executive Composite score of the parent/carer BRIEF-2 questionnaire. A sub sample of children with DCD (n = 16) and TD children (n = 13) also had results available from a teacher questionnaire and these showed significant differences between groups for eight out of thirteen of the subsections. The Inhibit, Self-Monitor, and Emotional Control scales as well as the Behavioural Regulation Index and the Emotional Control Index did not show significant group differences.

Analyses on the experimental measures, IDS-2-EF standardised battery of Executive Function, and parent BRIEF-2 questionnaire were run removing the eight children with co-occurring conditioned and their TD matched peers. The group differences on the AdFlanker Incongruent RT, which measured Interference Control requiring a motor response, were no longer significant. All other measures central to the research remained statistically significant. Individual profiles were then examined across all measures. Individual differences in the Executive Function performance of children with DCD was observed, with children varying in the percentage of their overall scores that fell 1 SD below the TD mean. However, overall children with DCD were found to have significantly poorer performance across all measures with 56% (14/25) of children in the DCD group scoring below 1 SD of the TD mean for more than half of the measures of Executive Function. The next chapter will discuss these findings in relation to the predictions made in chapter four (section 4.8) and the wider literature discussed in chapter four (section 4.3 – 4.7).

8. Study 1 Discussion. Executive Function in Children with and without DCD with a focus on Inhibition

8.1. Introduction

The aim of Study One was to examine the Executive Function skills of children with and without DCD with a focus on Inhibition. Previous research on this topic has suggested that children with DCD experience difficulties with Inhibition in comparison to TD peers, although several limitations to this work have been identified (see chapter four). Previous research studies have each focused on narrow aspects of Inhibition which is a multifaceted construct. Study One set out to examine Inhibition in a more systematic way using a comprehensive range of measures including experimental tasks aimed to isolate Inhibition from other components of Executive Function, a standardised battery of tasks, as well as parent/carer and teacher questionnaires. In Study One, experimental tasks were used to examine Inhibition in isolation from other components of Executive Function. In line with Nigg's (2000) taxonomy of Inhibition, outlined in chapter three (section 3.2.1), Inhibition was divided into Response Inhibition and Interference Control. Response Inhibition is the ability to override an automatic but unhelpful response and Interference Control is the ability to ignore distracting information. Response Inhibition and Interference Control tasks were further divided into those which require a motor response and those which require a verbal response. This enabled closer examination of the effect of response modality on a group of children with motor difficulties.

Tasks used to examine Response Inhibition and Interference control allowed for highly controlled environments where these components could be isolated as much as possible from other Executive Functions. Whilst this increased the level of experimental control and the validity of attributing the results to the component of interest, this lowered the ecological validity of the results as these environments are far removed from those of everyday life. Therefore, further measures were used to gain a comprehensive profile of Inhibition skills. The IDS-2 Executive Function component (IDS-2-EF) is a standardised battery aimed at investigating Inhibition working alongside other components of Executive Function in four tasks which are presented and scored in a standardised manner. The IDS-2-EF does not aim to isolate components from each other so therefore these tasks have a lower level of experimental control compared to the Response Inhibition and Interference Control tasks. However, they have a higher level of ecological validity as the components of Executive Function that are measured are more commonly used together to complete activities in everyday life. Parent/carer and teacher standardised questionnaires were also used to gain an understanding of Inhibition and Executive Function within everyday life. This combination of assessments enabled Inhibition to be assessed within the Unity and Diversity model of Executive Function outlined in chapter three (section 3.2).

Chapter four (section 4.8.) outlined twelve predictions based on theories of DCD and Executive Function, and the previous empirical work that has examined Inhibition in children with DCD. In the current chapter the findings from Study One are discussed in relation to these predictions. Chapter 7 (section 7.6.2.) also included additional analysis considering the impact of hyperactivity and inattention on the results. The discussion of the results of these analyses is not included in this chapter but is considered in the general discussion in chapter 11. In this chapter the performance of the groups under the most controlled conditions is first considered (experimental measures of Response Inhibition and Interference Control). This is followed by performance on the standardised battery of Executive Function. Finally, Executive Function and Inhibition specific skills in everyday life for each group are considered using results from parent/carer and teacher questionnaires.

8.2. Response Inhibition

Response Inhibition is the ability to override automatic but unhelpful responses. A task which assesses Response Inhibition presents one stimulus with two conflicting responses (Laloi et al., 2017). Chapter four reviewed the empirical work on Response Inhibition in children with DCD and highlighted the range of tasks used. Some of these tasks required a motor response and some a verbal response, however, few studies considered the impact of response modality on performance and included measures that required both a motor and verbal response. In Chapter four (Section 4.8.1) five predictions were made, relating to Response Inhibition and children with DCD based on previous empirical research findings. Results from Study One are considered below in relation to these predictions.

8.2.1. Motor Response

The AdVIMI Motor task incongruent condition was the measure of Response Inhibition. This task required children to respond to an image of a pointed finger by making a fist, and to an image of a fist by pointing their finger. The congruent condition was the control condition and required children to respond with the same gesture as the image (e.g. when the image was of a fist the child was required to make a fist).

8.2.1.1. Prediction One*.* Children with DCD will have higher error rates compared to TD peers for the Response Inhibition task which requires a motor response.

Findings from Study One are in line with prediction one as children with DCD were found to make significantly more errors than TD peers. Children with DCD were found to have a higher error rate in both the congruent condition (which did not have a Response Inhibition demand), and in the Incongruent condition (which did have a Response Inhibition demand). These results suggest that children with DCD perform with less accuracy in tasks that require a motor response (in this case a hand gesture) than TD peers. These results remained statistically significant when children with co-occurring conditions and matched TD controls were removed from the analysis. This provides evidence that the inclusion of children with Autism Spectrum Condition and Attention Deficit Hyperactivity Disorder cannot explain these results. This is not surprising as children with DCD are widely known to experience difficulties with the accuracy of their movements and this is often a difficulty which impacts their ability to complete everyday motor tasks (Blank et al., 2019). Using the original VIMI task Leonard et al. (2015) also found that children with DCD made more errors compared to TD peers. Unlike Study One which reported congruent and incongruent error rates separately, Leonard et al. (2015) used the total number of errors made across conditions as their measurement of Response Inhibition. However, errors in the congruent condition do not provide information about Response Inhibition skills.

The data were further analysed to examine the group by condition interaction. This analysis showed that children with DCD had a greater increase in their error rate between the congruent condition to the incongruent condition compared to TD controls. This suggests that the higher error rate of children with DCD in the Incongruent condition relates not just to their motor difficulties but to the increased demands of Response Inhibition, which has a greater impact on this group compared to TD controls. These results could provide evidence that these difficulties are related to the theory of limited attention capacity outlined in chapter two (section 2.4.1.1.) (Kahneman, 1973). This suggests that children with DCD performed more poorly than TD peers in the incongruent condition because they had less attention resources available to meet the additional Response Inhibition demand. This is because more attention was used to execute the motor response compared to TD peers.

8.2.1.2. Prediction Two. Children with DCD will have longer RT compared to TD peers for the Response Inhibition task which requires a motor response.

Whilst no previous research has investigated the RT of children with DCD and TD peers using the VIMI task, RT has been considered in other Response Inhibition tasks which required a motor response (key press, touch screen or foot pedal). Previous research findings have been inconsistent, with three studies finding significant differences in RT between those with DCD and TD controls using non-emotional stimuli (Mandich et al., 2003; Querne et al., 2008; Ruddock et al., 2015) and three not finding significant differences between the groups using non-emotional stimuli (Rahimi-Golkhandan et al., 2014, 2016; Thornton et al., 2018). The results of Study One are not in line with prediction two, as there were no significant group differences in Reaction Time in the AdVIMI Motor task. These findings suggest that whilst children with DCD have been found to make more errors than TD peers in this task, they do not take more time to react to the stimuli presented. All children were instructed to respond as quickly as possible to the stimulus presented. Study One (section 7.3.1.1.1.) also details results of correlational analysis between speed and accuracy for each group in the AdVIMI motor incongruent condition. This showed a moderate significant correlation between RT and accuracy for the TD group, indicating that longer reaction times were associated with lower error rates. No significant relationship was found in the

DCD group. This suggests that TD children may slow down their reactions in response to a challenging task, increasing their accuracy, but children with DCD do not appear to do this. Heitz, (2014) argues that the relationships between RT and error rate is a feature of the decision-making process. Participants set a criterion for decision making regarding the amount of evidence that is required to make a choice based on task demands and their internal goals. A relationship found between RT and error rate for the TD group but not the DCD suggests that children with and without DCD differ in their decision-making process. Qualitative observations of children with DCD completing this task highlighted that children often reacted and then paused in the air or moved without a specific purpose for longer compared to TD peers. This suggests that children with DCD did not have a plan before moving. In future it would be interesting to consider if children with DCD would make fewer errors if they were instructed to take more time to process the full task demands prior to reacting to a stimulus.

8.2.1.3. Prediction Three. Children with DCD will have longer MT compared to TD peers for the Response Inhibition task which requires a motor response.

Findings are in line with this prediction. Children with DCD had significantly longer MT compared to TD peers for both the congruent condition (control condition) and the incongruent condition (which assessed Response Inhibition). This aligns with the previously mentioned qualitative observations (section 8.2.1.2.) that, whilst children with DCD appeared to react at the same speed as TD children, they did not appear to have a plan for their actions. This resulted in longer MT as they spent longer with their hands in the air whilst they decided on their next action. Children with DCD are slower to complete many motor tasks, (American Psychiatric Association, 2013) and previous research has found that they spend longer with their pen 'in the air' when completing handwriting tasks (Prunty et al., 2014) which aligns with these findings. Further analysis showed that children with DCD also had a significantly larger increase in MT between the conditions compared to TD peers. This suggests that the addition of the Response Inhibition demand interfered with performance and further slowed down this process for children with DCD.

Chapter seven (7.3.1.1.) presents data on the relationship between MT and error rate for the AdVIMI motor incongruent condition for both groups. Interestingly for the TD group there was a moderate positive correlation between MT and error rate. This indicated longer MTs were associated with a greater number of errors. This suggests that longer MT may represent difficulty with the task for TD children. This could be because a longer MT for the TD group may have been the result of a greater number of 'corrected' responses. A 'corrected' response occurred when a child initially provided the wrong response and then corrected themselves. A 'corrected' response therefore took longer to perform and gained less points than when a correct response was given immediately. No significant correlations were found for the DCD group between MT and error rate.

8.2.2. Verbal Response

The AdVIMI verbal task incongruent condition was the measure of Response Inhibition which required a verbal component, this task required the child to respond with the word 'car' to an image of a doll, and with the word 'doll' to an image of a car. The congruent condition was the control condition and required children to correctly name the image displayed (e.g. say the word 'car' to an image of a car).

8.2.2.1. Prediction Four. Children with DCD will not differ from TD peers in their error rate for the Response Inhibition task which requires a verbal response.

Results from Study One did not support prediction four as the DCD group had significantly higher error rates than TD controls in the AdVIMI verbal incongruent condition. This result contrasts with Leonard et al. (2015) who found that children with DCD and TD controls did not differ in error rate on the VIMI verbal task. However, there were substantial differences in how error rate was calculated in Leonard et al's. (2015) research compared to Study One. Leonard et al. (2015) used the combined error rate of the congruent and incongruent conditions as their measure of error rate. Study One did not find a significant group difference in the congruent condition of the AdVIMI verbal task (which did not require Response Inhibition). Furthermore, Leonard et al. (2015) counted only correct and incorrect responses, whilst Study One included 'corrected' responses where a child may initially respond incorrectly and then self-correct to provide the right response. This suggests that the measures in Study One were more sensitive and may account for the different findings.

8.2.2.2 Prediction Five. Children with DCD will not differ from TD peers in their RT for the Response Inhibition task which requires a verbal response.

Results from Study One supported prediction five as there was no significant group effect for RTs. No previous research considered RT in a verbal Response Inhibition task. This prediction was made because it was reasoned that the Response Inhibition difficulties of children with DCD may be directly related to their motor difficulties (section 4.8.1). Whilst there was no group difference in RT there was a difference in error rate in this task (see section 8.2.2.1.). This suggests that Response Inhibition difficulties in children with DCD are present outside the context of a motor task but that RT is not effected.

8.2.3. Effect of Response Modality

It was reasoned in chapter four (section 4.8.1) that children with DCD may only experience difficulties with Response Inhibition when coupled with a motor task. This is because it was thought that Response Inhibition difficulties may be the result of a lack of skill automation and limited attentional capacity. However, results from Study One suggest that children with DCD experience Response Inhibition specific difficulties irrespective of response modality, although the nature of these difficulties is still unclear. The findings could be explained by the differences in brain activation patterns between the groups discussed in chapter two (section 2.4.1.3.). Differences have been found in children with DCD in brain regions responsible for both motor and Executive Function tasks (e.g. the cerebellum). It is also possible that difficulties with skill automation cause an additional challenge in Response Inhibition tasks with a motor response as a greater number of errors were made in the motor task compared with the verbal task.

Sartori, Valentini and Fonseca (2020) are the only authors to consider error rate in a verbal and motor Response Inhibition task, which was not the VIMI task. As in Study One, they found that children with DCD and TD peers made greater errors in a Response Inhibition task both with a motor (touch screen press) and verbal response. However, Sartori, Valentini and Fonseca (2020) included both a DCD group, with MABC-2 Test scores below the 5th percentile, and an ‘at risk of DCD’ group with scores between the 9th-16th percentile. Children in the ‘at risk’ group did not significantly differ in Response Inhibition skills to TD controls. This suggests that Response Inhibition skills may be related to severity of motor difficulty. In Study One, although the inclusion criterion for DCD was ≤ 16th percentile on the total MABC-2 Test, the group mean fell on the 2nd percentile and 76% of the sample had scores ≤ 5th percentile. It is possible that this high proportion of children with motor skills ≤ 5th percentile could explain why children with DCD made more errors on the AdVIMI verbal and motor components in Study One. Subsample analyses in chapter seven (sections 7.3.1.1.2. and 7.3.1.2.2.) contains descriptive statistics and analysis of group differences between the six children in the DCD group who scored between the 9th-16th percentile on the MABC-2 Test, and age and gender matched TD peers. Results of this analysis show that children with DCD who have motor skills between the 9th - 16th percentile on the MABC-2 Test still made significantly more errors in the AdVIMI verbal condition in comparison to TD peers. However, there were no significant group differences for the AdVIMI motor component. It is interesting that this group performed more poorly on the Response Inhibition task requiring a verbal response only, however, to understand this result fully further information on areas such as language skills would be required. These results suggest that the severity of motor difficulties in children with DCD do not have an impact on Response Inhibition when a verbal response is required but potentially have an effect when a motor response is required. The results of Study One add to the limited body of research which has examined the effect of response modality on Response Inhibition in children with DCD and TD peers, and is the first to directly consider the impact of the severity of motor difficulties on the results found.

8.3 Interference Control

Interference Control is the ability to ignore distracting information to meet the demands of a task. A task which assesses Interference Control presents two conflicting dimensions with only one relevant to the task (Laloi et al., 2017). Chapter four (section 4.4.) outlined the results of research which had examined Interference control in children with DCD and highlighted the range of tasks used. Some of these tasks required a motor response and some a verbal response, however, prior to Study One no research had considered the impact of response modality on performance or included measures that required both a motor and verbal response. Chapter four also outlined four predictions (section 4.8.2.) related to Interference Control and children with DCD based on previous research. Results from Study One will be considered below in relation to these predictions.

8.3.1. Motor Response

The Motor Interference Control task was the incongruent condition of the AdFlanker task in which children had to press a touch screen button to correctly identify the direction the middle fish was pointing and ignore the distracting fish which were pointing in the opposite direction. In the congruent condition, which did not require Interference Control, all of the fish pointed in the same direction.

8.3.1.1. Prediction Six. Children with DCD will have higher error rates compared to TD peers in motor Interference Control.

Results from Study One did not support prediction six as the DCD group did not make significantly more errors than TD peers. The task used was the AdFlanker, this was an adapted version of a Flanker task that was carefully designed to assess Interference control in children aged six to ten years, whilst limiting external variables such as attention to the screen and engagement in the task. This finding contrasts with Michel et al. (2018) who found that children with motor difficulties made more errors on a Flanker task compared to TD peers. There are several possible explanations for this difference in findings. Participants in Michel et al's. (2018) study were younger (four to six years) than those in Study One (six to ten years). Therefore, it is possible that accuracy on the AdFlanker is impaired for younger children with motor difficulties but not for older children with DCD. Another possibility for the differences in findings relates to differences in the task demands. The Flanker task used by Michel et al. (2018) had a higher error rate than the AdFlanker used in this research. It is possible that Michel et al.'s (2018) Flanker had a higher error rate because their Flanker task had both a 'standard' condition and a 'switch' condition. In the standard condition, children were required to respond to the direction of the middle fish when the fish were red; in the switch condition, children were required to respond to the direction of the flanking fish, when the fish were yellow. Michel et al. (2018) also had conditions in which the target fish was presented alone, and a condition in which the target fish was presented alongside star fish. Michel et al. (2018) reported that children with motor difficulties made more errors on the standard Flanker presentation. However, it is possible that their performance was also influenced by the requirement of remembering the switch rule for yellow fish as well as the other conditions. In comparison the AdFlanker aimed to isolate Interference Control from other domains (e.g. working memory and attention) as much as possible. The AdFlanker had only two conditions, the congruent condition (in which all the fish faced the same direction) and the incongruent condition (in which the middle fish faced the opposite direction to the flanking fish). When designing a task aimed to isolate Interference Control from other domains, it is difficult to balance the need to make a task engaging while ensuring the task presents an adequate challenge. Differences in error rate between those with motor difficulties/DCD compared to TD peers have been found in the majority of other research which have used Interference control tasks which require a motor response (Mandich et al., 2002; Tsai, Pan et al., 2009). However, Mandich et al. (2002) and Tsai, Pan et al. (2009) used a Simon task which has a greater requirement from motor skills compared to the Flanker task.

8.3.1.2. Prediction Seven. Children with DCD will have longer RT compared to TD peers in Motor Interference Control.

Results from Study One support prediction seven, the DCD group had significantly longer RTs on the AdFlanker task compared to TD peers. However, this was found for both the congruent and incongruent conditions. No significant group difference was found in relation to the increase in RT between the congruent and incongruent conditions. This demonstrates that children with DCD were slower at reacting in this task regardless of the Interference Control demand. Chapter 6 Table 6.7. displays results of between group analysis which show that children with DCD had poorer visuomotor quality scores on the IDS-2 motor component. Children with DCD have also been found to have poorer visual perception skills when a motor component was not required (Prunty et al., 2016b). Therefore, it is possible that the slower RT of children with DCD in the AdFlanker task is as a result of poorer visual perception which is required to quickly locate the target fish and interpret its direction, rather than poorer Interference Control skills. In Study One, when the subsample analysis was performed removing children with co-occurring conditions which can affect attention (Attention Deficit Hyperactivity Disorder (ADHD) and

Autism Spectrum Condition (ASC)) group differences for RT were no longer significant. This is the only performance task in which removing children with co-occurring conditions significantly altered the results.

8.3.2. Verbal Response

The verbal Interference Control task used in Study One was the AdAC incongruent condition. This required children to respond with the correct colour of the animal despite its presenting colour (e.g. to say 'blue' to a picture of a red dolphin).

8.3.2.1. Prediction Eight. Children with DCD will not differ from TD peers in their verbal Interference Control error rate.

The results from Study One supported prediction eight as there was no significant group difference in error rate. However, like in the AdFlanker task both groups made very few errors. Interference Control with a verbal response has been investigated in three previous studies (Alesi et al., 2019; Michel et al., 2011; Pratt et al., 2014). Supporting the current findings, Alesi et al. (2019) and Pratt et al. (2014) did not find a group difference in error rate, but Michel et al. (2011) did report a group difference. It was also reasoned in chapter four (section 4.8.2) that if theories of skill automation and limited attention explained Interference Control difficulties this would not extend to verbal tasks. However, these results need to be interpreted with caution, firstly because predicting a null effect can be problematic as it is difficult to support a negative result. Furthermore, it is possible that the task was too easy to elicit differences between the groups.

8.3.2.2. Prediction Nine. Children with DCD will not differ from TD peers in their verbal Interference Control completion time.

Findings from Study One did not support prediction nine as it was found that children with DCD had longer completion times than TD peers on the incongruent condition. There was no group difference on completion time for the congruent condition which did not require Interference Control. This suggests that the longer completion time for children with DCD in the incongruent condition was caused by difficulties with the additional Interference Control demand. When relationships between error rate and completion time for the AdAC task were examined in each group individually, a significant positive moderate correlation was found for the DCD group. This indicated that longer completion times were associated with higher error rates. This suggests that longer completion time in the DCD group was an indicator of poorer performance and not that children with DCD were taking longer to match the accuracy of their TD peers. No significant correlations were found for the TD control group.

8.3.3. Effect of Response Modality

Significant group differences were found on Interference Control tasks which required both a motor and a verbal response. However, the clearest evidence of Interference Control difficulties in children with DCD from Study One was in the task that required a verbal response. This is because a difference between the groups on completion time were found only in the incongruent condition of the verbal task. In the motor task longer RTs were found for both the congruent and incongruent conditions, suggesting that the longer RT of the incongruent condition may not be because of Interference Control difficulties. Due to the low error rate in both the verbal and motor tasks, and the different measurement of time used in both tasks, results could not be directly compared to examine the influence of different response modalities on results. The finding that children with DCD took longer to complete the Interference Control task which required a verbal response does suggest that children with DCD do experience difficulties with Interference Control irrespective of the motor demands of the task. This suggests that explanations such as skill automation difficulties and limited attentional capacity cannot fully explain the Interference control difficulties experienced by children with DCD.

8.4 Standardised Test Battery

A range of standardised batteries exist to examine Executive Function, these include the NIH Toolbox Flanker (Gershon et al., 2009) and Delis-Kaplan Executive Function System (Delis et al., 2001). This research has used the Executive Function component from the IDS-2 (IDS-2-EF). The IDS-2-EF aims to examine Executive Function components, including Inhibition, working together. No previous research has employed a standardised battery of Executive Function aimed to consider Inhibition working alongside other components of Executive Function in children with DCD.

8.4.1. Prediction 10 Children with DCD will have poorer scores on a standardised battery of Executive Function which aims to assess Executive Function components working together.

Prediction 10 was made on the basis that difficulties with Executive Function in everyday life have been reported in children with DCD as well as difficulties within tasks aimed to assess individual components of Executive Function (Blank et al., 2019). Inhibition was the component of focus of Study One and the IDS-2-EF was used to examine Inhibition working alongside other components of Executive Function. The IDS-2 has four tasks:

1. Listing Words (in which children are required to list as many words as possible from a particular category)
2. Divided Attention (in which children are required to list as many animals as possible and simultaneously cross out parrots from a sheet of distractors)
3. Animal Colours (in which children must say the correct colour of the animal despite the presenting colour)
4. Drawing Routes (in which children are required to complete mazes without lifting their pen from the page or drawing over the same part of the route more than once).

Each has a different ‘primary’ component which is utilised to a larger extent than other components during that task, however, the IDS-2-EF does not aim to isolate components from each other. The ‘Animal Colours’ task is the task which has Interference Control as a primary component of focus. Group differences have already been reported for the AdAC task in section 8.3.2, however, the task is measured differently here. To a lesser extent Inhibition is also utilised in the other three tasks. Specific predictions were not made for each of the four tasks due to the lack of prior research aimed at investigating components of Executive Function working in combination. Chapter seven (section 7.4) outlined that the mean scores for each of the four tasks were poorer for the DCD group compared to the TD group. However, the group differences were only statistically significant on two measures: the Animal Colours task (time) and the Divided Attention task (number of animals listed). No significant differences were found between the groups on the ‘Listing Words’, task, ‘Divided Attention’ (number of parrots crossed out) or the ‘Drawing Routes’ task time or quality.

As previously mentioned, whilst the IDS-2-EF assesses Executive Function components working in combination, rather than as isolated components, the demands on each Executive Function component are not equal across tasks. The ‘Animal Colours’ task has similar demands to the Fruit Stroop task (Röthlisberger et al., 2010) which is commonly used to assess Interference Control. Michel et al. (2011), found similar results using the Fruit Stroop task to those reported in Study One using the ‘Animal Colours’ task. Michel et al. (2011) found that children with motor difficulties had significantly longer reaction times than TD peers on the incongruent condition of the Fruit Stroop task. However, reaction time is not recorded in the IDS-2 ‘Animal Colours’ task, which uses the following equation to measure performance $incongurent\ time - \frac{(congurent \times grey)}{(congurent + grey)}$. This equation takes into consideration performance on the other trials of the task which do not have an Interference control demand. For example, the ‘grey’ condition in which the primary component assessed is working memory as children are required to recall the correct colour of the animals when they are presented in grey. Therefore, unlike the Fruit Stroop task, the IDS-2 Animal Colours task does not give an isolated Interference Control score. Despite not assessing Interference Control in isolation the IDS-2-EF ‘Animal Colours’ task, compared to other tasks in the IDS-2-EF, relies the most heavily on Interference Control. Therefore, poorer Interference Control skills could explain why children with DCD had significantly poorer performance on this task.

Children with DCD performed significantly more poorly on the ‘Divided Attention’ listing animals task compared to TD peers. The ‘Divided Attention’ task consists of two tasks to be completed simultaneously: listing different animals and crossing out parrots. For this task, Mental Flexibility is the primary component of Executive Function assessed, as it requires children to switch flexibly between two tasks. Children with DCD listed fewer animals but crossed out a similar number of parrots compared to TD peers. This suggests that children with DCD had difficulties with the Mental Flexibility required for this task and tended to focus on the completion of one task more than the other. This resulted in children crossing out a similar number of parrots as TD children but failing to list the same number of animals. The IDS-2-EF task ‘Listing Words’ has similar demands to a verbal fluency task (Diamond, 2013) and also assesses Mental Flexibility as the primary Executive Function component, because it requires children to think flexibly and (for older children) to switch between mental sets (e.g. listing fruits and vegetables and items of transport alternately). However, unlike in the ‘Divided Attention’ task, children with DCD were not found to significantly differ in the number of words listed in this task compared to TD peers. Leonard et al. (2015) also used a verbal fluency task which required children with DCD and TD peers to list as many words as possible that began with a specified letter and did not find a significant group difference. This suggests that the poorer performance of children with DCD on the ‘Divided Attention’ listing animals task may not be solely because of poorer Mental Flexibility.

In the ‘Divided Attention’ task children with DCD had poorer performance in one of the two measures, this suggests that they focused attention on one task (crossing out parrots) to the detriment of the other (listing animals). If children with DCD found performing two tasks at the same time difficult it is likely that each child would choose to focus on a different part of the task. However, it appears children with DCD predominantly chose to focus attention on crossing out parrots rather than listing animals, as evidenced by the significant difference in the number of words listed but not in the number of parrots crossed out. As part of the wider IDS-2 battery, not reported in this research, children were required to complete a task called ‘Processing Speed – Parrots’ which required them to cross out parrots quickly without stopping to list words (full details in Appendix A). It is possible that children had difficulties overriding their impulse to keep crossing out parrots (as they had done previously) to stop and think of an animal to list. This suggests that poorer Response Inhibition skills in children with DCD influenced their poorer score on the IDS-2 Divided Attention – Listing Animals task.

There was no significant group difference on the IDS-2-EF ‘Drawing Routes’ task for time or quality scores. This task required children to complete mazes quickly and accurately without drawing over the same part of the route more than once. The primary component of Executive Function this task aims to assess is Planning. This result is surprising considering, in Study One, both the parent/carer and teacher questionnaire reported that children with DCD had poorer planning skills in everyday life compared to TD peers. However, Appendix P displays the results of relationships between the parent/carer and teacher scale of the BRIEF-2 questionnaire that assesses planning and the ‘Drawing Routes’ time and quality scores. This shows no significant relationships were found between the performance task and questionnaire. This is supported by previous findings which reported low correlations between questionnaire and performance measures (Toplak et al., 2013). Debate exists regarding whether planning is a distinct component of Executive Function or whether planning is the result of Executive Function components working in combination towards a goal (Diamond, 2013; Henry & Bettenay, 2010). These different perspectives on how to define planning results in difficulties assessing the validity of tasks that aim to assess this component. The sensitivity of the 'Drawing Routes' quality score is also low as a child who makes three or more errors is given the same score as a child who makes an unlimited number of errors or who is unable to complete the task. This may have affected the ability to detect differences between the groups in the quality component of the task.

8.5. Questionnaire

The BRIEF-2 Questionnaire parent/carer and teacher forms consider a range of behaviours associated with Executive Function skills in everyday life at home and at school. Each questionnaire has 63 items that cover nine domains (see chapter six section 6.3.2.2.) Most of the items are identical between parent/carer and teacher forms with only six questions specific to each. Items on the Inhibit scale enquire about behaviours such as acting 'wild and out of control', being able to 'put the breaks on actions,' and getting 'out of control more than friends'. Chapter 7 section 7.5.1 and 7.5.2. reported the proportions of children in each group who scored within the BRIEF-2 US standardisation categories of 'mildly elevated', 'potentially clinically elevated' and 'clinically elevated' for the Global Executive Function composite and the Inhibit scale. However, these are based on US norms and may not be directly applicable to a UK population.

8.5.1. Prediction 11, Parent/Carer Questionnaire Children with DCD will have poorer parent/carer reported Inhibition than TD peers.

Results for the parent/carer questionnaire support Prediction 11. Children with DCD were rated as having poorer Executive Function skills on all scales, indexes and the Global Composite Score of the BRIEF-2 parent/carer questionnaire compared to TD peers. This suggests that children with DCD have greater difficulties with everyday activities that require Executive Function and Inhibition specifically in their home lives. Although the clinical categories for the BRIEF-2 are based on US norms, they do indicate that a large proportion (60%) of children from the DCD group had GEC scores that were at least potentially clinically relevant. This proportion was over seven times that for the TD group. The proportion of children in the DCD group with at least potentially clinically relevant scores on the Inhibit scale (16%) was also double that of the TD group. This indicates that for many of the children with DCD the Executive Function and Inhibition specific difficulties found in study one are potentially clinically relevant and are negatively affecting their everyday home lives. No previous research has considered the parent/carer reported Inhibition skills of children with DCD and TD peers aged six to ten years. However, the finding that individuals with DCD have overall poorer Executive Function skills in everyday life is supported by research with adolescents (O'Dea & Connell, 2016) and children aged three to five years (Houwen et al. 2017). However, Houwen et al. (2017) did not find group differences in parent/carer reported Inhibition specifically. It is important to note that O'Dea and Connell's (2016) participants were much older than those in Study One and Houwen et al.'s (2017) were younger. Therefore, results are not directly comparable due to the protracted development of Executive Functions (see chapter three section 3.3.).

There is evidence that Executive Function in children younger than six years old aligns more closely to a unitary construct (Hughes et al., 2010; Wiebe et al., 2008) with evidence of Inhibition emerging as a distinct component from age six (Messer et al., 2018). This potentially questions the validity of research aiming to investigate Inhibition in a group of children younger than six years old. A further potential explanation of the differences in results could be that the Inhibition expectations for children aged three to five years is manageable for children with DCD, however, as the expectations increase with age this is when difficulties with Inhibition begin to emerge. Longitudinal research to track the development of children's motor and Executive Function skills with a focus on Inhibition would be useful to provide greater understanding of the age differences reported. This research could also provide information regarding whether developmental spurts in motor and Inhibition skills appear to be related. It could also further the understanding of the relationships between motor and Executive Function skills, and whether these differ for children with DCD and TD peers.

8.5.2 Prediction 12, Teacher Questionnaire Children with DCD will have poorer teacher reported Inhibition skills compared to TD peers.

Results from Study One did not support Prediction 12. Teacher perspectives were considered as well as parent/carer perspectives because it has been reported that both have differing perspectives. Low to moderate correlations between parent/carer and teacher reports have previously being found on the BRIEF-2 (Gioia et al., 2015). Sixteen children with DCD and thirteen TD children, from the full sample of fifty children, had results from both the parent/carer and teacher forms for the BRIEF-2. Appendix O outlines correlations between the two forms. Low to moderate correlations were found, with only the Shift and Initiate scales having non-significant correlations. Moderate correlations were found for both the Inhibit and Global Executive Composite score.

Results from Study One show that children with DCD had poorer overall teacher reported Executive Function skills, measured by the Global Executive Composite score. The proportion of those with at least potentially clinically elevated scores was more than four times that of the TD group. However, unlike results from the parent/carer questionnaire, no significant group differences were found in teacher reported Inhibition skills. Whilst no study to date has investigated both teacher and parent/carer perspectives of Executive Function skills in children with DCD and TD controls within the same sample, differences between parent/carer and teacher report have been found in many behavioural rating scale questionnaires (De Los Reyes & Kazdin, 2005).

There are various possible explanations for the differences in response from parents/carers and teachers. One possibility is that the predictable structure of the school environment, compared to the home environment, could provide additional support for children with Inhibition difficulties. It has been found that interventions that aim to reduce unpredictability and increase daily structure, such as visual schedules, improve the ability of children with Autism Spectrum Condition to maintain focus on school tasks and increase productivity (Macdonald et al., 2018). This suggests that an increase in structure and predictability in the home environment may reduce the behavioural difficulties children with DCD are reported to experience at home. Many schools also have explicit rules and behavioural conduct codes that are written into school policy. It maybe that children with DCD are better able to adapt their behaviour such as acting 'out of control' and talking 'at the wrong time' when it is very clear when these behaviours are allowed and when they are not allowed. Children with DCD are reported to have higher levels of social and communication difficulties (Blank et al., 2019) so therefore they may experience greater challenges to TD peers in following rules which are implicit (more common at home) rather than explicit (more common at school).

It is also possible that teachers have different priorities to parents/carers, and this impacts the extent to which teachers take notice of different behaviours. Children with DCD were reported by teachers to have poorer skills in domains of Executive Function such as Organisation of Materials, Planning and Working Memory. It is possible these areas are of greater priority in the school environment. Therefore, teachers were better able to identify difficulties in these areas, and they may perceive these to have had a more direct impact on children's attainment and on task behaviour than Inhibition. A further possible explanation for the difference found between the parent/carer and teacher questionnaires could relate to the sample of children for whom teacher questionnaires were returned. It is possible that this group systematically differed from the overall sample, including a higher proportion of TD children whose teachers were concerned about their Inhibition skills. The proportions of children with at least potentially clinically elevated Inhibit scores were very similar across the DCD and TD groups, with the TD group having the a highest proportion. This suggests that the group of TD children whose teachers returned the questionnaire had an unusually large proportion of children with poorer Inhibition. This may explain why no differences between the groups were found on the teacher questionnaire in Study One. Further support for this argument comes from the similar percentages of children in the DCD group with scores which were at least 'potentially clinically elevated' on the parent (16%) and teacher (18%) questionnaire. It is also possible that the smaller sample size of children with a teacher questionnaire (DCD = 16, TD = 13) impacted the ability to detect statistically significant group differences on this measure.

8.6. Overall Profile of Performance

Study One determined cut off points for each task, using 1 SD from the mean of the TD group. A child's performance was rated as 'average', 'above average' or 'below average' for each task and this was displayed using a heatmap (chapter seven Figure 7.11.). It was found that children with DCD had a significantly greater proportion of scores that fell in the 'below average' range, compared to TD peers. Over half of the children with DCD (14/25) had more than 50% of their scores fall in the below average range. No child in the TD group had over half of their scores fall in the below average range. This suggests that children with DCD do experience difficulties with Executive Function with a focus on Inhibition. This also highlights the individual differences in performance within the DCD group, as eleven out of the twenty-five children in the DCD group had less than 50% of their scores fall into the 'below average' range. This shows the importance of using a range of measures to measure this complex construct and increase the ability to detect differences between groups.

As mentioned previously, over half of children with DCD had over 50% of their Executive Function scores from Study One in the 'below average' range. This group included six children with co-occurring conditions and eight children with no reported co-occurring conditions. It was also found throughout the research that, other than RT in the AdFlanker task and a few scales and indexes of the BRIEF-2 questionnaires, removing children with co-occurring conditions did not affect the results found. This suggests that the presence of co-occurring conditions do not fully explain the poorer Executive Function skills of children with DCD compared to TD peers. In Figure 7.11. (in chapter 7) each group was ordered from the fewest 'below average' scores to the most 'below average' scores across all measures excluding the teacher questionnaire. In the DCD group the children with the fewest 'below average scores' (DCD 16, 2, 22, 17, 14, 26, 19, 07, Figure 7.11) appear to have difficulties on the BRIEF-2 parent/carer Cognitive Regulation Index which is the sum total of the Initiate, Working Memory, Plan, Task Monitor and Organisation of Materials scales. However, these children did not have difficulties on the scales of the Behavioural Control Index (Inhibit, Self-Monitor) or the Emotional Regulation Index (Shift and Emotional Control). This suggests that Executive Function skills in everyday life related to cognitive regulation could have an even greater frequency in DCD than Inhibition difficulties which are related to behavioural control. These children were found to experience difficulties across some Inhibition performance tasks (in particular the AdVIMI verbal error rate) and some measures of the IDS-2 Executive Function component (in particular Divided Attention – Listing Animals).

Overall, 23 out of 25 children in the DCD group (92%) had at least 25% of their scores across all measures (excluding the teacher questionnaire) 1 SD below the mean, compared to four out of 25 (16%) children in the TD group. This suggests that children with DCD experience greater difficulties with Executive Function in comparison to their TD peers and the presence of co-occurring conditions does not explain this difference. These results suggest that potentially there is a relationship between motor and Inhibition skills, as DCD is characterised by motor difficulties. Furthermore, it is possible that differences in the profile and severity of motor difficulties in children with DCD may help to explain why some children with DCD appear to have difficulty with a wider range of tasks in comparison to others.

8.7. Overall Summary

Study One has found that children with DCD aged six to ten years have poorer Inhibition skills than age and gender matched TD peers on some of the measures investigated.

8.7.1. Experimental Tasks

- Children with DCD had difficulties with Response Inhibition that required both a motor and verbal response, as well as Interference Control which required a verbal response.
- This suggests that children with DCD have difficulties with Inhibition which are evident even outside of the context of a motor task.
- Therefore, difficulties with skill automatisation and limited attention capacity, are unable to wholly explain the Inhibition difficulties observed.

8.7.2. Standardised Battery of Executive Function

- Children with DCD were found to have difficulties with tasks which appeared to have higher Inhibition demands (e.g. the Animal Colours task).
- This suggests that children with DCD have difficulties in tasks which do not isolate the Executive Function components but have a substantial Inhibition requirement.

8.7.3. Parent/Carer and Teacher Questionnaire

- Children with DCD were reported to have poorer overall Executive Function skills effecting everyday life in both a teacher and parent/carer questionnaire.
- Inhibition difficulties were only noted on the parent/carer questionnaire and not the teacher questionnaire.

It is unknown why children with DCD were found to have Inhibition difficulties reported on the parent questionnaire but not the teacher questionnaire. However, this could be because of the high percentage of children in the TD group with at least 'potentially clinically elevated' scores on the teacher questionnaire. It is also possible that the sample size of children with teacher questionnaires effected the ability to detect significant group differences.

8.7.4. Overall Profile of Performance

- Children with DCD were found to have more 'below average' scores compared to TD peers. Over 50% (14/25) of the children with DCD had scores which were 'below average' for over half the Executive Function measures used, and over 90% (23/25) had 'below average' scores for at least a quarter of the items.
- Collectively children with DCD have been found to experience poorer EF skills. However, in group variation in the extent and pattern of these difficulties is evident.
- It is unknown why some children with DCD appear to have more pronounced difficulties than others (evidenced by low scores on more items). Some previous research found Inhibition difficulties in children whose motor skills fall ≤ 5th percentile, but not in children whose motor skills fall between the 9th and 16th percentile in a standardised test of motor performance (Sartori, Valentini & Fonseca, 2020). In Study One when results from the experimental tasks were examined in the subsample of six children with less severe motor difficulties (9th - 16th percentile) and six TD controls, children with DCD were found to make significantly more errors on the AdVIMI verbal task but no other significant group differences were found.

- This suggests that there is potentially a relationship between Inhibition and motor skills.

To gain a thorough understanding of the nature of Inhibition difficulties experienced by children with DCD it is important to ascertain if Inhibition difficulties are related to the severity or profile of motor performance. The next chapter provides the results of exploratory analyses investigating relationships between motor skills and Inhibition.

9. Study Two Results: An Exploratory Study of Relationships between Inhibition and Motor Skills

9.1. Introduction

The literature review presented in chapter five revealed that whilst relationships between Inhibition and motor skills have been previously reported, findings have not been consistent across the literature. Some studies examined relationships only within samples of children with DCD or TD groups rather than across the two samples, this limited the range of scores available and the extent to which relationships could be found. Limitations are also evident, similar to those raised in relation to the research examining Inhibition skills in those with DCD and TD peers. These include: the wide range of measures used across studies, the lack of examination of response modality (verbal vs. motor), and the disparity between how performance is measured (time vs. accuracy). No study has yet examined relationships between Inhibition and motor skills across measures that comprehensively assess Inhibition including Response Inhibition, Interference Control and parent/carer and teacher report. The aim of Study Two was therefore to examine the relationships between Inhibition and motor skills in children with and without DCD using a comprehensive range of measures.

The results from Study Two are presented in this chapter. Relationships between Inhibition and motor skills are examined across the two groups together, and statistically significant relationships are then examined within the DCD and TD control groups separately. Examining relationships within each group allows for the comparison of relationships between Inhibition and motor skills for those with DCD and TD peers. It also provides further understanding regarding the nature of the relationships found. Inhibition measures included Response Inhibition and Interference control tasks which require both a motor and verbal response as well as parent/carer and teacher reported Inhibition skills. For the experimental tasks, only the incongruent conditions were used for analysis, as this is the condition which examined Inhibition. This chapter is organised into sections according to the different areas of motor assessment: overall motor skills, gross motor skills and ball skills, fine motor skills, and drawing skills.

9.2. Data Analysis

The data analysis techniques that have been used were outlined and justified in chapter six (section 6.5.2.). Bi-variate correlational analyses was used to examine relationships between Inhibition and motor skills. Relationships were examined across the entire sample and when a statistically significant relationship was found, relationships were then considered in each group separately. Due to the different measures used some relationships are positive and some are negative, however, all significant relationships indicate that poorer Inhibition skills were associated with poorer motor skills. Appendix R provides details of full p values, and when parametric analysis has been used 95% confidence intervals for the relationships reported for the entire sample.

9.3. Overall Motor Skills

Bivariate correlations were used to examine potential relationships between measures of Inhibition and overall motor skills, measured by the MABC-2 Test Total standard score (SS).

9.3.1. Response Inhibition

9.3.1.1. AdVIMI Motor. Pearson correlation found a significant negative relationship between the ADVIMI motor error rate and MABC-2 Test Total score for the entire sample ($n = 50$) ($r = - 48$, $p < .001$), indicating that greater errors on the AdVIMI motor task were associated with poorer overall motor skills. Using Spearman correlation, a negative relationship was also found between AdVIMI motor MT and MABC-2 Test Total SS for the entire sample ($r_s = -.37$, $p = .009$). This relationship indicates that a longer ADVIMI motor MT was associated with poorer overall motor skills. Relationships were also examined separately for each group. Within the DCD group a significant relationship was found to remain between the AdVIMI motor error rate and MABC-2 Test Total SS ($r = -.48$, $p = .013$). No relationships were found to remain significant when examined in the TD group.

9.3.1.2. AdVIMI Verbal. Spearman correlation found a negative relationship between AdVIMI verbal error rate and MABC-2 Test Total SS for the entire sample ($n = 50$) ($r_s = - .55$, $p < .001$) indicating that the poorer a child’s motor skills the greater number of errors they made. No significant relationship was found between AdVIMI verbal RT and MABC-2 Test Total SS. This relationship was also examined for each group separately and was not found to remain significant in either group.

9.3.2. Interference Control

9.3.2.1. AdFlanker. Spearman correlation found a significant negative relationship between the AdFlanker RT and MABC-2 Test Total SS for the full sample (n = 50) (r_s = - .37, p = .009), indicating that a longer AdFlanker RT was associated with poorer overall motor skills. No significant relationship was found between AdFlanker error rate and MABC-2 Test Total SS. This relationship was also examined separately for each group. Within the DCD group the significant relationship remained between AdFlanker RT and MABC-2 Test Total SS (r = -.46, p = .021). No significant relationship was found to remain when examined in the TD group.

9.3.2.2. AdAC. A Spearman correlation found a significant negative relationship between the AdAC completion time and MABC-2 Test Total SS for the entire sample (n = 50) (r_s = - 47, p ≤ .001), indicating that longer AdAC completion times were associated with poorer overall motor skills. No significant relationship was found between the AdAC error rate and MABC-2 Test Total SS. This relationship was also examined for each group separately and was not found to remain significant in either group.

9.3.3. Behavioural Rating Inventory of Executive Function 2nd Edition (BRIEF-2) Questionnaires

High scores on the BRIEF-2 questionnaires are indicative of poor performance whereas high scores on the MABC-2 Test are indicative of good performance.

9.3.3.1 Parent/Carer Questionnaire. A Spearman Correlation between the BRIEF-2 parent/carer Inhibit scale and the MABC-2 Test Total SS for the entire sample (n = 50) found a significant negative correlation (r_s = -56, p ≤ .001). This indicates that poorer parent/carer reported Inhibition skills in everyday life were associated with poorer motor skills. This relationship was then examined separately for each group. Within the TD group the relationship was found to remain significant between the MABC-2 Total Test SS and the Inhibit scale (r_s = -

.43, p = .030). No relationship was found to remain significant when examined in the DCD group.

9.3.3.2. Teacher Questionnaire. A Spearman correlation between the BRIEF-2 teacher Inhibit scale and the MABC-2 Test Total SS for the entire sample (DCD =16, TD = 13) did not find a significant relationship (r_s = -23, p = .238).

9.3.4. Overall Motor and Inhibition Skills Summary

This section provided results of correlational analysis between measures of Inhibition and overall motor skills. All significant correlations indicate that poorer Inhibition skills were associated with poorer overall motor skills. Measures of Response Inhibition and Interference Control which required both a motor and verbal response, as well as parent/carer reported Inhibition skills were found to relate to overall motor skills. No relationship was found between teacher reported Inhibition skills and overall motor skill. Relationships were examined for each group separately. Within the DCD group significant relationships were found between measures of Response Inhibition and Interference Control which required a motor response and overall motor skills. Within the TD group a significant relationship was found between parent/carer reported Inhibition skills and overall motor skills.

9.4. Gross Motor and Ball Skills

Gross motor skills were organised differently in the two motor assessments used (See chapter six section 6.3.1.). Chapter 6 Table 6.6. displays the different sections of the IDS-2 Psychomotor component. For gross motor performance an overall score is achieved based on the performance of tasks which include: balancing, jumping, catching, and throwing. Chapter 6 Table 6.3. displays the different components of the MABC-2 Test. Gross motor skills are assessed in the balance component (which is based on the performance of three balance tasks). The MABC-2 Test also has a separate aiming and catching component, which is considered here under gross motor skills. Therefore, the measures of gross motor skills used were: IDS-2 Gross Motor component (IDS-2-GM), MABC-2 Test Balance Total (MABC-2 Bal), MABC-2 Test Aiming and Catching (MABC-2 A&C). Higher scores on both the IDS-2 and MABC-2 Test indicate better performance.

9.4.1. Response Inhibition

Table 9.1. displays the correlations between Response Inhibition measures and measures of gross motor skills for the entire sample (n = 50).

9.4.1.1. AdVIMI Motor. Significant negative relationships were found between AdVIMI motor error rate and IDS-2-GM and MABC-2 A&C for the entire sample. This indicates that a greater number of errors on the AdVIMI motor task was associated with poorer gross motor skills on these measures. Significant negative correlations were also found between AdVIMI motor RT and IDS-2-GM and MABC-2 Bal indicating that slower AdVIMI motor RT was associated with poorer gross motor skills but not aiming and catching measured on the MABC-2. Significant negative correlations were also found between AdVIMI motor MT and all measures of gross motor skills (IDS-2-GM; MABC-2 Bal and MABC-2 A&C). This indicated that slower MT on the AdVIMI motor task was associated with poorer gross motor skills on all measures.

Relationships were also examined separately for each group. Within the DCD group significant negative relationships remained between the AdVIMI motor error rate and IDS-2-GM ($r = - .45$, $p =.025$), as well as AdVIMI motor RT and IDS-2-GM ($r = .42$, $p = .036$) and AdVIMI MT and IDS-2-GM ($r_s = - .52$, $p = .008$). This indicated that slower and less accurate performance on the AdVIMI motor task within the DCD group was associated with poorer motor skills measured on the IDS-2-GM. Within the TD group a significant negative correlation remained between AdVIMI motor RT and MABC-2 Bal ($r_s = - .44$, $p = .030$), indicating that longer AdVIMI Motor RT was associated with poorer balance skills in the TD group.

9.4.1.2. AdVIMI Verbal. Spearman correlations found significant negative relationships between AdVIMI verbal error rate and all measures of gross motor skills (IDS-2-GM, MABC-2 Bal and MABC-2 A&C) for the entire sample. This indicated that a greater number of errors on the AdVIMI verbal task was associated with poorer gross motor skills on all measures Significant negative relationships were also found between AdVIMI verbal RT and MABC-2 Bal, indicating that slower Verbal RT was associated with poorer balance skills for the entire sample. Relationships were also examined separately for each group. No relationships remained significant for either the DCD or TD group.

Table 9.1.

Correlations between the AdVIMI Response Inhibition Tasks and Gross Motor Tasks for the DCD and TD groups Combined (n = 50)

Response Inhibition	Gross Motor Measures		
	IDS-2-GM	*MABC-2 Bal*	*MABC-2 A&C*
Motor – Incongruent			
AdVIMI Motor Error	*-.52****$_1$	*- .21*	*-.35***$_1$
AdVIMI Motor RT	*- .31**$_1$	*- .37***	*-.023*$_1$
AdVIMI Motor Movement Time	*- .51****	*- .37***	*- .52****
Verbal – Incongruent			
AdVIMI Verbal Error	*- .47****	*- .42***	*- .36***
AdVIMI Verbal RT	*- .24*	*- .41***	*-.24*

Note: IDS-2GM = IDS-2 Gross Motor

Component point score; MABC-2 Bal = MABC-2 Test Balance Total SS; MABC-2 A&C = MABC-2 Test Aiming and Catching SS

$_1$ = Pearson Correlation (otherwise Spearman)

*p ≤ .05; ** p ≤ .01; *** p ≤.001

9.4.2. Interference Control

Table 9.2. displays results of correlational analysis between Interference Control tasks and measures of gross motor skills for the entire sample (n = 50).

9.4.2.1. AdFlanker. The AdFlanker is an Interference Control task which requires a motor response. Spearman correlations found a significant negative relationship between AdFlanker error rate and IDS-2-GM indicating that a greater number of errors in the AdFlanker Task was associated with poorer gross motor skills measured on the IDS-2-GM. Spearman correlations also found significant negative relationships between AdFlanker RT and all measures of gross motor skills (IDS-2-GM, MABC-2 Bal and MABC-2 A&C) for the entire sample This indicated that longer AdFlanker RT for the entire sample were associated with poorer gross motor skills.

Relationships were also examined separately for each group. Within the DCD group relationships between the AdFlanker RT and the IDS-2-GM (r_s = - 54, p = .005); and MABC-2 Bal (r_s = - .52, p = .008) remained significant. No significant relationships were found when examined in the TD group.

9.4.2.2. AdAC. The AdAC task is an Interference control task which requires a verbal response. Spearman correlations found significant negative relationships between AdAC completion time and all measures of gross motor skills (IDS-2-GM, MABC-2 Bal and MABC-2 A&C) for the entire sample. This indicates that longer AdAC completion time was associated with poorer gross motor skills. No significant correlations were found between AdAC error rate and any of the measures of gross motor skills across the entire sample.

Relationships were also examined separately for each group. Within the TD group a significant negative correlation was found between AdAC completion time and IDS-2 gross motor skills (r_s = - .43, p = .034) indicating that slower AdAC completion time was associated with poorer gross motor performance on these measures. Relationships were also examined separately for each group. No other significant correlations remained in either group.

Table 9.2.

Spearman Correlations between Interference Control Tasks and Gross Motor Skills for DCD and TD groups Combined (n = 50)

Interference Control	Gross Motor Measures		
	IDS-2-GM	*MABC-2 Bal*	*MABC-2 A&C*
Motor – Incongruent			
AdFlanker Error Incongruent	*- .30**	*.04*	*-.18*
AdFlanker RT Incongruent	*- .51****	*- .50****	*-.34**
Verbal – Incongruent			
AdAC Error Incongruent	*.04*	*- .16*	*.04*
AdAC Completion Time Incongruent	*- .47****	*- .44****	*-.34**

Note: IDS-2GM = IDS-2 Gross Motor Component point score; MABC-2 Bal = MABC-2 Test Balance Total SS; MABC-2 A&C = MABC-2 Test Aiming and Catching SS

*p ≤ .05; *** p ≤ .001

9.4.3. Behavioural Rating Inventory of Executive Function 2nd Edition (BRIEF-2) Questionnaires

High scores on the BRIEF-2 questionnaires are indicative of poor performance whereas high scores on the IDS-2 Psychomotor component and MABC-2 Test are indicative of good performance. Table 9.3. displays the results of correlational analysis for the entire sample between the BRIEF-2 parent/carer (n = 50) and teacher (n = 29) questionnaires for the Inhibit scale and measures of gross motor skills for the entire sample

9.4.3.1. Parent/Carer Questionnaire. Significant negative correlations were found between parent/carer reported Inhibition skills and all measures of gross motor skills = (IDS-2-GM, MABC-2 Bal, and MABC-2 A&C). Relationships were also examined separately for each group. For the TD group significant negative relationships were found to remain between the parent/carer BRIEF-2 Inhibit scale and the IDS-2-GM (r_s = - .39, p = .052), and the MABC-2 Bal (r_s = -

.45, p = .026). No relationships remained significant when examined in the DCD group.

9.4.3.2. Teacher Questionnaire. A spearman correlation between the BRIEF-2 teacher Inhibit scale and the IDS-2-GM measure of gross motor skills found a significant negative correlation between teacher reported Inhibition skills and IDS-2-GM gross motor skills for the entire sample. This indicates that poorer Inhibition skills were associated with poorer gross motor skills on this measure. No significant relationships were found between the BRIEF-2 teacher Inhibit scale and any of the other measures of gross motor skills. This relationship was also examined for each group separately and was not found to remain significant in either group.

Table 9.3.

Correlations, for DCD and TD groups combined, between Gross Motor Measures and the BRIEF-2 Parent/Carer (n = 50) and Teacher (n =29) Inhibit Scale

BRIEF-2 Form	Gross Motor Measures					
	IDS-2-GM		*MABC-2 Bal*		*MABC-2 A&C*	
Parent/Carer (n = 50)	r_s	*- .47****	*r*	*- .49**	r_s	*- .41***
Teacher (n = 29)	r_s	*- .36**	r_s	*- .02*	r_s	*- .08*

Note: IDS-2GM = IDS-2 Gross Motor Component point score; MABC-2 Bal = MABC-2 Test Balance Total SS; MABC-2 A&C = MABC-2 Test Aiming and Catching SS

*** p < .001; * p = .05

9.4.4. Gross Motor and Inhibition Skills Summary

This section provided results of correlational analysis between Inhibition and measures of gross motor skills, including Aiming and Catching skills. All significant correlations indicate that poorer gross motor skills were associated with poorer Inhibition skills. Measures of gross motor skills were found to significantly relate to some measures of Response Inhibition and Interference Control as well as parent/carer and teacher reported Inhibition skills for the entire sample. Relationships were also examined for each group separately. Within the DCD group significant relationships were found between measures of Response Inhibition and Interference control which require a motor response, and measures of gross motor skills. Within the TD group significant relationships were found between Response Inhibition with a motor response, Interference Control with a verbal response, and parent/carer reported Inhibition and measures of gross motor skills.

9.5. Fine Motor Skills

Fine motor skills are included in the two motor assessments used. Chapter 6 Table 6.6. details the tasks used in the IDS-2 and Table 6.3. details the tasks used in the MABC-2 Test. In the IDS-2 there are separate scores for the time and quality of fine motor performance. The measures of fine motor skills used were therefore: IDS-2 Fine Motor Time (IDS-2-FM-T), IDS-2 Fine Motor Quality (IDS-2-FM-Q) and MABC-2 Test Manual Dexterity component score (MABC-2 MD). Higher scores indicate better performance.

9.5.1. Response Inhibition

Table 9.4. displays results from correlational analysis between the Response Inhibition tasks and the fine motor measures for the entire sample (n = 50).

9.5.1.1. AdVIMI Motor. Pearson correlations, and where assumptions were not met Spearman correlations, found significant negative relationships between AdVIMI motor error rate and all measures of fine motor skills (IDS-2-FM-Q, and IDS-2-FM-T, MABC-2 MD) for the entire sample. These relationships indicate that a greater AdVIMI motor error rate was associated with poorer fine motor performance across all measures. A Spearman correlation also found a significant negative relationship between AdVIMI motor MT, IDS-2-FM-T, and MABC-2 MD, indicating that slower completion time on the AdVIMI motor task was associated with poorer scores for ID2-FM-T and MABC-2 MD for the entire sample. Relationships were also examined separately for each group. Significant negative relationships remained for the DCD group between AdVIMI motor error rate and MABC-2 MD (r = - .52, p = .007). No relationships remained significant when examined in the TD group.

9.5.1.2. AdVIMI Verbal. Spearman correlations found significant negative relationships between AdVIMI verbal error rate and all measures of fine motor skills (IDS-2-FM-T, IDS-2FM-Q and MABC-2 MD). These relationships indicated that greater error rate on the AdVIMI verbal task was associated with poorer fine motor skills on these fine motor measures for the entire sample. No significant negative relationships were found between AdVIMI verbal RT and any of the fine motor skills measures. Relationships were also examined separately for each group. A significant negative relationship remained between AdVIMI verbal error rate and IDS-2-FM-Q (r_s = - .45, p = .023) for the DCD group. No relationships remained significant when examine in the TD group.

Table 9.4.

Relationships between Response Inhibition Tasks and Fine Motor Measures for DCD and TD groups Combined (n = 50)

Response Inhibition	Fine Motor Measures		
	IDS-2-FM-T	*IDS-2-FM-Q*	*MABC-2 MD*
Motor – Incongruent			
AdVIMI Motor Error	*- .44***1*	*- .34**	*-.60***1*
AdVIMI Motor RT	*- .18*	*- .22*	*.08*
AdVIMI Motor Movement Time	*- .33**	*- .20*	*-.34**
Verbal Incongruent			
AdVIMI Verbal Error	*- .28**	*- .46****	*.52****
AdVIMI Verbal RT	*- .25*	*- .16*	*.07*

Note: IDS-2-FM-T = IDS-2 Fine Motor Time point score; IDS-2-FM-Q = IDS-2 Fine Motor Quality point score; MABC-2 MD = MABC-2 Test Manual Dexterity SS

*p ≤ .05; **≤ .01; *** p ≤.001

1 = Pearson Correlation (otherwise Spearman)

9.5.2. Interference Control

Table 9.5. displays results from correlational analysis between Interference Control tasks and measures of fine motor skills for the entire sample (n = 50).

9.5.2.1. AdFlanker. Significant negative correlations were found between AdFlanker RT and IDS-2-FM-T (r_s = - 33, p = .019) indicating that longer RT for the

AdFlanker task was associated with slower time scores for the IDS-2 fine motor task. No other significant correlations were found between the AdFlanker task and measures of fine motor skills for the whole sample. This relationship was also examined separately for each group. Within the DCD group the significant negative relationship remained between Flanker RT and IDS-2-FM-T (r = - 46, p = .021). No significant relationship remained when examined in the TD group.

9.5.2.2. AdAC. A Spearman correlation found a significant negative relationship between the AdAC error rate and IDS-2-FM-T (r_s = - 29, p = .040) indicating that more errors in the AdAC task were associated with slower time scores for the IDS-2 fine motor task. Spearman correlation also found significant correlations between AdAC completion time and all measures of fine motor skills (IDS-2-FM-T, IDS-2-FM-Q and MABC-2 MD). This showed that longer completion times on the AdAC task were associated with poorer fine motor skills. Relationships were also examined separately for each group. Significant negative relationships remained for the DCD group between AdAC completion time and IDS-2-FM-T (r_s = - .56, p = .004) and AdAC error rate and IDS-2-FM-T (r_s = - .43, p = .031). No significant relationships remained when examined in the TD group.

Table 9.5.

Spearman Correlations between Interference Control Tasks and Fine Motor Measures for DCD and TD groups Combined (n = 50)

Interference Control	Fine Motor Measures		
	IDS-2-FM-T	*IDS-2-FM-Q*	*MABC-2 MD*
Motor – Incongruent			
AdFlanker Error	*.07*	*-.10*	*-.26*
AdFlanker RT	*-.33**	*-.22*	*-.20*
Verbal – Incongruent			
AdAC Error	*-.29**	*-.21*	*-.09*
AdAC Completion Time	*-.44****	*-.31**	*-.32**

Note*:* IDS-2-FM-T = IDS-2 Fine Motor Time point score; IDS-2-FM-Q = IDS-2 Fine Motor Quality point score; *MABC-2* MD = MABC-2 Test Manual Dexterity task SS

*p ≤ .05; *** p ≤.001

9.5.3. Behavioural Rating Inventory of Executive Function 2nd Edition (BRIEF-2) Questionnaires

High scores on the BRIEF-2 questionnaires are indicative of poor performance whereas high scores on the IDS-2 psychomotor component and MABC-2 Test are indicative of good performance.

9.5.3.1. Parent/Carer Questionnaire. Spearman correlations were performed between the BRIEF-2 parent/carer questionnaire Inhibit scale and measures of fine motor skills for the entire sample (n = 50). Significant negative correlations were found between the BRIEF-2 parent/carer Inhibit scale and MABC-2 MD (r_s = -.33, p = .020), and IDS-2 Fine Motor Quality (r_s = - .50, p < .001). This indicates that poorer parent/carer reported Inhibition skills were associated with poorer fine motor skills on those measures. No significant correlations were found between the BRIEF-2 parent/carer Inhibit scale and IDS-2-FM-T. Relationships were also examined separately for each group. No significant relationships were found between the parent/carer BRIEF-2 Inhibit scale and any of the fine motor measures for either group.

9.5.3.2. Teacher Questionnaire. Spearman correlations were performed between the BRIEF-2 teacher questionnaire Inhibit scale and measures of fine motor skills for the entire sample (n=29). A significant negative correlation was found between the BRIEF-2 teacher Inhibit scale and the MABC-2 MD (r_s = - .43, p = .02) indicating that poorer teacher reported Inhibition skills were associated with poorer fine motor skills on the MABC-2 Test component. No significant correlations were found between the BRIEF-2 parent/carer Inhibit scale and the other fine motor measures. The significant relationships were also examined separately for each group. No significant relationships were found between the parent/carer BRIEF-2 Inhibit scale and any of the fine motor measures for either group.

9.5.4. Fine Motor and Inhibition Skills Summary

This section provided results of correlational analysis between fine motor skills and measures of Inhibition. All significant correlations indicate that poorer Inhibition skills were associated with poorer fine motor skills. Measures of fine motor skills were found to significantly relate to measures of Response Inhibition, Interference Control and parent/carer and teacher reported Inhibition skills for the entire sample. Relationships were also examined for each group separately. Within the DCD group significant relationships were found between measures of fine motor skills and verbal and motor Response Inhibition and Interference Control measures. No relationships remained significant when examined in the TD group.

9.6. Drawing Skills

Chapter 6 Table 6.6. details the three sets of tasks used to assess ‘visuomotor’ skills in the IDS-2 (drawing trails, copying images and completing mirror images). As these all involve drawing with a pen, performance is referred to here as measuring ‘drawing’ skills. (Although the MABC-2 Manual Dexterity component score includes a drawing task, this is not considered separately in the analyses as performance on a single measure may be less reliable). In the IDS-2 there were separate scores for the time and quality of drawing performance. Therefore, the measures of drawing skills used were: IDS-2 Visuomotor Time (IDS-2-VM-T) point score and IDS-2 Visuomotor Quality point score (IDS-2-VM-Q).

9.6.1. Response Inhibition

Table 9.6. displays results from correlational analysis between Response Inhibition tasks and measures of drawing skills for the entire sample (n=50).

9.6.1.1. AdVIMI Motor. A significant negative correlation was found between AdVIMI motor error rate and IDS-2-VM-Q for the entire sample. This relationship indicates that more errors on the AdVIMI motor task were associated with poorer quality drawing performance. No significant relationships were found between any of the measures of drawing skills and AdVIMI motor movement time or RT. Relationships were also examined for each group separately. Within both the DCD group ($r = -.41$, $p = .042$) and TD group ($r = .50$, $p = .011$) significant negative correlations remained between AdVIMI motor error and IDS-2-VM-Q ($r = -.41$, $p = .042$).

9.6.1.2. AdVIMI Verbal. Spearman correlations found significant relationships between AdVIMI verbal error rate and IDS-2-VM-Q. This relationship indicated that more errors on the AdVIMI verbal task were associated with poorer quality drawing skills for the entire sample. No significant relationships were found between AdVIMI verbal RT and any of the drawing measures. The significant relationship between AdVIMI verbal error rate and IDS-2-VM-Q was also examined for each group separately and was not found to remain significant in either group.

Table 9.6.

Relationships between Response Inhibition Tasks and Drawing Tasks for DCD and TD groups Combined (n = 50)

Response Inhibition	Drawing Measures	
	IDS-2-VM-T	*IDS-2-VM-Q*
Motor – Incongruent		
AdVIMI Motor Error Incongruent	*-.20*	*-.53****
AdVIMI Motor RT Incongruent	*-.12*	*.01*[1]
AdVIMI Motor Movement Time Incongruent	*-.12*	*-.25*
Verbal – Incongruent		
AdVIMI Verbal Error Incongruent	*.08*	*-.33**
AdVIMI Verbal RT Incongruent	*-.14*	*-.11*

Note: IDS-2-VM-T IDS-2 Visuomotor time point score; IDS-2-VM-Q IDS-2 Visuomotor Quality point score

*p ≤ .05; **≤ .01; *** p ≤.001

[1] = Pearson Correlation (otherwise Spearman)

9.6.2. Interference Control

9.6.2.1. AdFlanker. Spearman correlation found a significant negative relationship between AdFlanker RT and IDS-VM-Q (r_s = - .32, p = .024), indicating that a slower AdFlanker RT was associated with poorer IDS-2-VM-Q scores for the entire group. No significant correlations were found between AdFlanker error rate and measures of drawing skills. The significant relationship between AdFlanker RT and IDS-2-VM-Q was also examined for each group separately and was not found to remain significant in either group.

9.6.2.2. AdAC. No significant correlations were found between AdAC error rate and measures of drawing skills.

9.6.3. Behavioural Rating Inventory of Executive Function 2nd Edition (BRIEF-2) Questionnaires

High scores on the BRIEF-2 questionnaires are indicative of poor performance whereas high scores on the IDS-2 psychomotor component are indicative of good performance.

9.6.3.1. Parent/Carer Questionnaire. Spearman correlations found significant relationships between the BRIEF-2 parent/carer Inhibit scale and IDS-2-VM-Q (r_s = - .45, p = .001) for the entire sample, indicating that poorer parent/carer reported inhibition skills were associated with poorer quality drawing skills. No significant correlation was found between the BRIEF-2 parent/carer Inhibit scale and IDS-2-VM-T. The significant relationship between the BRIEF-2 parent/carer Inhibit scale and IDS-2-VM-Q was also examined separately for each group. No relationships were found to remain significant for either group.

9.6.3.2. Teacher Questionnaire. No significant correlation was found between the BRIEF-2 parent/carer Inhibit scale and measures of drawing skills.

9.6.4. Drawing and Inhibition Skills Summary

This section provided results of correlational analysis between drawing skills, and measures of Inhibition. All significant correlations indicate that poorer Inhibition skills were associated with poorer drawing skill. The IDS-2 Visuomotor Quality score was found to significantly relate to some measures of Response Inhibition and Interference Control which required a motor and verbal response as well as to parent/carer reported Inhibition skills. Significant relationships were examined for each group separately. Within both the DCD and TD groups significant negative correlations remained between AdVIMI motor error and IDS-2-VM-Q. No other relationships remained significant when examined within each group separately.

9.7. Summary

This chapter has shown the results of correlational analyses to determine if there is a relationship between Inhibition and motor skills and, if so, if relationships differ for those with and without DCD. Motor skills were divided into: overall motor skills, gross motor skills (including ball skills), fine motor skills, and drawing skill. Inhibition was examined using Response Inhibition and Interference Control performance tasks which required both a motor and verbal response, as well as parent/carer and teacher report. Table 9.7. displays the significant relationships which were found between Inhibition and all areas of motor skills across the entire group, indicating that poorer motor skills were associated with poorer Inhibition skills. When examined across the entire sample all areas of motor skills had at least one significant correlation to all areas of Inhibition (except overall motor skills and teacher reported Inhibition). However, relationships were not found across all measures.

Table 9.8. displays the significant relationships which were found when relationships were investigated in each group separately.

Within the DCD group significant relationships were found between:

- Overall motor skills and measures of Response Inhibition and Interference control which required a motor response.
- Gross motor skills and Response Inhibition and Interference Control which required a motor response
- Fine motor skills and Response Inhibition and Interference Control which required both a motor and verbal response
- Drawing skills and Response Inhibition which required a motor response

Within the TD group significant relationships were found between:

- Overall motor skills and parent/carer reported Inhibition skills.
- Gross motor skills and parent/carer reported Inhibition skills, measures of Response Inhibition with motor responses, and Interference Control with a verbal response
- Drawing skills and Response Inhibition with a motor response.

No significant relationships were found between fine motor skills and measures of Inhibition within the TD group.

Table 9.7.

A Summary of Relationships Between Motor and Inhibition Measures across DCD and TD groups Combined

		Overall	***Gross Motor***			***Fine Motor***			***Drawing***	
		MABC-2-Total	*IDS-2-GM*	*MABC-2 Bal*	*MABC-2 A&C*	*IDS-2-FM-T*	*IDS-2-FM-Q*	*MABC-2 MD*	*IDS-2-VM-T*	*IDS-2-VM-Q*
AdVIMI	Motor Error	■	■		■	■	■	■		■
	Motor RT		■	■						
	Motor Movement Time		■	■	■	■		■		
	Verbal Error	■	■	■	■	■	■	■		■
	Verbal RT			■						
Ad Flanker	Error Incongruent		■							
	RT Incongruent	■	■	■	■	■				■
AdAC	Error Incongruent					■				
	Completion Time Incongruent	■	■	■	■	■	■	■		
BRIEF-2	Parent/Carer Inhibit	■	■	■	■		■	■		■
	Teacher Inhibit		■					■		

Note: IDS-2: IDS-2-GM = IDS-2 Gross Motor Component point score; IDS-2-FM-T = IDS-2 Fine Motor Time point score; IDS-2-FM-Q = IDS-2 Fine Motor Quality point score; IDS-2-VM-T = IDS-2 Visuomotor Time point score; IDS-2-VM-Q = IDS-2 Visuomotor Quality point score

MABC-2 Test: MABC-2-Total = MABC-2 Test Total SS; MABC-2 Bal = MABC-2 Test Balance Total SS; MABC-2 A&C = MABC-2 Test Aiming and Catching SS; MABC-2 MD = MABC-2 Test Manual Dexterity SS

Shading indicates a significant relationship

Table 9.8.

A Summary of Relationships Between Motor and Inhibition Measures for DCD and TD groups Separately

		Overall	***Gross Motor***			**Fine Motor**			**Drawing**	
		MABC-2 Total	*IDS-2-GM*	*MABC-2 Bal*	*MABC-2 A&C*	*IDS-2-FM-T*	*IDS-2-FM-Q*	*MABC-2 MD*	IDS-2-VM-T	IDS-2-VM-Q
AdVIMI	Motor Error	DCD	DCD	Not examined				DCD	Not examined	DCD, TD
	Motor RT	Not examined	DCD	TD	Not examined	Not examined	Not examined	Not examined	Not examined	Not examined
	Motor Movement Time	Not examined	DCD				Not examined		Not examined	Not examined
	Verbal Error						DCD		Not examined	
	Verbal RT	Not examined	Not examined		Not examined	Not examined	Not examined	Not examined	Not examined	Not examined
Ad Flanker	Error Incongruent	Not examined		Not examined	Not examined	Not examined	Not examined	Not examined	Not examined	Not examined
	RT Incongruent	DCD	DCD	DCD		DCD	Not examined	Not examined	Not examined	Not examined
AdAC	Error Incongruent	Not examined	Not examined	Not examined	Not examined	DCD	Not examined	Not examined	Not examined	Not examined
	Completion Time Incongruent		TD			DCD			Not examined	Not examined
BRIEF-2	Parent/Carer Inhibit	TD	TD	TD		Not examined			Not examined	
	Teacher Inhibit	Not examined		Not examined	Not examined	Not examined	Not examined		Not examined	Not examined

IDS-2: IDS-2-GM = IDS-2 Gross Motor Component point score; IDS-2-FM-T = IDS-2 Fine Motor Time point score; IDS-2-FM-Q = IDS-2 Fine Motor Quality point score; IDS-2-VM-T = IDS-2 Visuomotor Time point score; IDS-2-VM-Q = IDS-2 Visuomotor Quality point score

MABC-2 Test: MABC-2-Total = MABC-2 Test Total SS; MABC-2 Bal = MABC-2 Test Balance SS; MABC-2 A&C = MABC-2 Test Aiming and Catching SS; MABC-2 MD = MABC-2 Test Manual Dexterity SS

Significant relationship for DCD group · Significant relationship for TD Group · No significant relationship for either group · Relationship not examined

10. Study Two Discussion: An Exploratory Study of Relationships between Inhibition and Motor Skills

10.1. Introduction

The main aim of Study Two was to examine relationships between Inhibition and motor skills in children with and without DCD. The findings from Study One, together with previous research has shown that children with DCD experience greater difficulties, in comparison to age and gender matched TD peers, on a range of Inhibition tasks. This includes Response Inhibition and Interference Control both when a motor and verbal response is required, and parent/carer reported Inhibition skills. These findings suggest that Inhibition difficulties may co-occur with the motor difficulties in children with DCD. However, unlike the motor difficulties that must be present for a diagnosis of DCD, not all children in the DCD sample were found to have the same Inhibition difficulties in Study One. Whilst 56% of children with DCD had over half their scores fall in the 'below average' range', this also means that 44% of children with DCD had most of their scores fall in the average range.

As outlined in chapter two children with DCD vary in the severity as well as the profile of their motor difficulties. Some children have less severe difficulties (between 9th – 16th percentile on the MABC-2 Test) and some more severe motor difficulties (<1st – 5th percentile on the MABC-2 Test), and these may manifest in just one domain (e.g. fine motor skills) or across all areas of motor skills. When results from the experimental tasks were examined in a subsample of six children with less severe motor difficulties (9th - 16th percentile) and six TD controls, fewer significant group differences were found. Furthermore, some previous research has found Inhibition difficulties in children whose motor skills fall ≤ 5th percentile, but not in children whose motor skills fall between the 9th and 16th percentile in a standardised test of motor performance (Sartori, Valentini & Fonseca 2020). This suggests that there is potentially a relationship between Inhibition and motor skills. Therefore, it is important to investigate relationships between motor and Inhibition skills across the different domains of motor skills to develop a more detailed understanding of the patterns of relationships. Gaining a better understanding of the relationships between Inhibition and motor skills could potentially influence the direction of future intervention research for children with DCD.

Chapter three (section 3.3.) outlined the developmental trajectory of Executive Function which increases in early childhood through to early adulthood and then decreases in older adults (Diamond, 2013). This is similar to the developmental trajectory of motor skills which also have a protracted developmental period with peak performance in young adulthood (Leversen et al., 2012). As other skills such as language (Park et al., 2002) do not follow this similar trajectory this has led to assumptions that Executive Function and motor skills are interrelated (Stuhr et al., 2020). Whilst research has shown a link between these two domains (van der Fels et al., 2015), the literature review in chapter five highlighted that there is currently no consensus regarding relationships between the Inhibition component of Executive Function and motor skills in children. Furthermore, Stuhr et al. (2020) found evidence that relationships between Executive Function and motor skills differ for pre-school children compared to adults. This suggests that the interrelationships between Inhibition and motor skills may also fluctuate depending on the ability level of the group under investigation (Stuhr et al., 2020). This could be because Executive Function skills are used to solve tasks with greater complexity and when motor performance is poor, motor tasks present a greater challenge and therefore require greater Executive Function demands compared to when tasks are more familiar or automated (Stuhr et al., 2020). This suggests that relationships between Inhibition and motor skills for children with DCD and TD peers may differ.

In Study Two Inhibition was investigated through experimental tasks of both Response Inhibition and Interference Control as well as parent/carer and teacher questionnaires of Inhibition skills in everyday life. Experimental tasks included those that required a motor response and those which required a verbal response, to examine whether response modality effected the relationships observed. The motor skills assessed included: overall motor skills, gross motor and ball skills, fine motor skills, and drawing skills. Previous research examining relationships between Inhibition and motor skills have not used measures of both Response Inhibition and Interference Control within the same sample and none have considered the effect of response modality. Houwen et al.'s (2017) study is the only one to have considered relationships between parent/carer reported Inhibition and motor skills, however, they used a sample of children aged three to five years. Research examining the developmental trajectories of Executive Function and Inhibition outlined in chapter two suggest that children aged three to five years (the age of participants in Houwen et al.'s (2017) study and children aged six to ten years (the age of participants in Study Two) are at differing stages in the development of Inhibition. This effects the ability to generalise Houwen et al.'s (2017) findings to older children. Study Two was exploratory in nature as limited work has investigated the relationships between Inhibition and motor skills. It took a systematic approach by considering relationships between multiple components of Inhibition (Response Inhibition, Interference Control and Inhibition in everyday life) and multiple domains of motor skills (overall motor skills, gross motor, fine motor, and drawing skills). It was anticipated that this examination of relationships between Inhibition and various domains of motor skills in Study Two would deepen the understanding of the Inhibition skills of children with DCD.

10.2. Methodological Issues

Several general methodological issues need to be discussed before considering the results of Study Two. These relate to: the type of analyses employed (correlational), the sample (i.e. within or across groups), as well as the sensitivity and range of scores in the motor and Inhibition measures.

Previous research which informed Study Two used correlational analysis to examine relationships between Inhibition and motor skills. The aim of Study Two was to explore this work further by using a broader range of measures and including children with a broader range of motor skills. Whilst some previous research has also used regression analysis (Cook et al., 2019; Houwen et al., 2017; Livesey et al., 2006; Piek et al., 2004; Riggs et al., 2013; Rigoli et al., 2012; Simpson et al., 2019; Stuhr et al., 2020) to further investigate the relationships between Inhibition and motor skills, this was often to control for confounding variables such as age, which was not necessary in Study Two because a narrower age range was used compared to some previous studies. The relationship between Inhibition and motor skills is a complex one and not currently very well understood. There are potentially other mediating factors that have not been measured in this research, rather than better skills in one area directly influencing the other. A significant relationship could be explained, for example, by children with better motor skills, compared to those with poorer motor skills, participating in more challenging sporting activities which also require (and therefore increase) Inhibition skills. Therefore, it was reasoned that correlational analysis was the most appropriate to meet the aim of this research and would be interpreted with the caution necessary when examining such a complex topic. Despite the limitations of correlational research, it can contribute to an understanding of how these domains relate, to form the basis of future work which will be discussed later in chapter 11 (section 11.3. and 11.6.).

In line with recommendations by Houwen et al. (2017) and Geuze et al. (2015), relationships were examined across children with and without DCD (see chapter 9 Table 9.7). This increases the range of scores available and therefore strengthens the ability to detect relationships. However, Study One found that children with DCD had poorer performance than TD controls on a range of Inhibition measures including Response Inhibition and Interference control experimental tasks and a parent/carer questionnaire. Therefore, it is possible that significant relationships may be caused by these differences between the groups (as children with DCD have both poorer motor and poorer Inhibition skills) rather than reflecting a meaningful relationship between Inhibition and motor skills. Statistically significant relationships were then assessed in each group separately (See chapter 9 table 9.8). Results were considered meaningful if: 1) a significant relationship was found across the groups, and Study One did not find a significant difference between the groups on that Inhibition measure, or 2) if a significant relationship was found across the groups and also in either the DCD or TD group separately. However, it is important to note that detecting relationships in each group separately is challenging due to the limited range of scores available for many of the measures (see Appendix N Tables N.8 and N.9).

Motor assessments usually focus on detecting differences at either the lower or higher end of performance (French et al., 2018). A primary rationale for this research was to further the understanding of children with DCD, therefore it was reasoned that motor assessments which have a greater sensitivity to detect differences in lower end performance would be more appropriate when examining relationships between Inhibition and motor skills.

The MABC-2 Test is widely used in clinical practice to identify children with DCD and was one of the two motor assessments used in Study Two. The MABC-2 has been widely used in previous research investigating relationships between Inhibition and motor skills. However, the MABC-2 has been found to have ceiling effects at the top end of performance and to be best at detecting differences at the lower end of motor skills (French et al., 2018). Therefore, detecting relationships using this measure in the TD group is more challenging.

The IDS-2 Psychomotor component is also a test which was designed for clinical use, to identify children with motor difficulties and was therefore also designed to have greater sensitivity to lower end performance. IDS-2 point scores were used for analysis which increased the range of scores available in comparison to standard scores. However, despite the larger range of scores available in comparison to standard scores, the scoring was not always able to capture the full range of performance. For example, in the gross motor task a child who was unable to walk along the rope, falling off continually, would achieve the same score as a child who was able to carefully perform this task but stepped off the rope more than twice. This affected the sensitivity to measure differences in performance both within and between the groups.

There are also important considerations to highlight in relation to the Inhibition measures used. To assess Inhibition a mix of experimental tasks aimed to assess Response Inhibition and Interference control were used as well as parent/carer and teacher questionnaires. The range of scores achieved in the experimental tasks differed for each group, which affected the ability to detect relationships between Inhibition and motor skills equally for each group. The range of scores achieved, for example, in the DCD group for the AdFlanker RT Interference Control task was much larger (1.89s – 3.72s) compared to the TD group (1.91s – 2.60s). Across both groups low error rates were found for Interference Control tasks which also affects the ability to detect relationships. It is important to be mindful of these methodological limitations as the results of Study Two are discussed below.

10.3. Overall Motor Skills

Study One examined performance on experimental measures of Inhibition between a subsample of children with DCD with motor skills between the 9th and 16th percentile and age and gender matched TD peers. In this subsample children with DCD were found to have a higher error rate on the AdVIMI verbal task. No other statistically significant differences between the groups, which were found when examined in the complete sample, were found when examined in the subsample. Previous research has also found that children with overall motor skills that fall ≤ 5th percentile had difficulties with Inhibition skills that were not evident for children whose motor skills fell between the 9th – 16th percentile (Sartori, Valentini & Fonseca 2020). In Study Two, relationships between Inhibition and overall motor skills were therefore examined to further the understanding regarding whether the severity of motor difficulty may impact on the relationship with Inhibition skills. Relationships between Inhibition and overall motor skills were measured using the total score of the MABC-2 Test which is a composite of the scores across different domains. This is the most frequently used measure in previous research on this topic but with varying results. Although the IDS-2 Psychomotor component was used to examine areas of gross motor, fine motor and visuomotor/drawing skills, it was not possible to consider an overall score from this test as standard scores and total 'Psychomotor' score were not available at the time of writing. In previous research, eight studies have examined relationships between Inhibition and overall motor skills (Alesi et al., 2019; Houwen et al., 2017; Livesey et al., 2006; Michel et al., 2018; Piek et al., 2004; Pratt et al., 2014; Rigoli et al., 2012; Stein et al., 2017), with only half finding significant relationships (Livesey et al., 2006; Michel et al., 2018; Rigoli et al., 2012; Stein et al., 2017).

The overall motor score formed part of the inclusion criteria outlined in chapter six. Children with DCD were required to have an overall motor score at or below the 16th percentile on the MABC-2 Test and TD children were required to have an overall motor score above the 16th percentile on the MABC-2 Test. Therefore, the range of scores available in each group for overall motor skills was narrow. This effected the ability to detect relationships within each group when examined separately. When relationships were examined across the entire sample significant relationships were found between overall motor skills and Inhibition

(Response Inhibition, Interference Control, parent/carer and teacher report). All relationships indicated that poorer Inhibition performance was associated with poorer overall motor performance. However, when examined within groups separately, only three relationships remained significant, the relationships between AdVIMI motor and overall motor skill, and AdFlanker RT and overall motor skills in the DCD group and between parent/carer reported Inhibition and overall motor skills in the TD group.

A relationship between Interference control with a motor response (AdFlanker) and overall motor skills in children with DCD is aligned with findings from Michel et al. (2018) who found a relationship between performance on a Flanker task and overall motor skills in children with motor difficulties. However, Pratt et al. (2014) also investigated relationships between Interference Control and overall motor skills in children with DCD and did not find a relationship. However, Pratt et al. (2014) included a sample of children aged six to fourteen years and developmental differences could have affected the ability to detect relationships. The results from Study Two suggest that better overall motor skills in the DCD group are associated with a faster RT on the AdFlanker task. Results not remaining when examined in the TD group suggest that increases in motor skills beyond a certain point (16^{th} percentile) are not associated with increases in performance. This indicates that for those with the poorest motor skills there may be an association between overall motor skills and Inhibition which is not present for those with average to good motor skills.

Study Two also found a significant relationship between parent/carer reported Inhibition skills and overall motor skills when examined in the TD group separately. This was not found when examined within the DCD group separately. This indicates that better everyday Inhibition skills at home are associated with better overall motor skills only for those with motor skills above the 16^{th} percentile. This could be because children with the best motor skills may be likely to have good skills in a range of other areas including Inhibition. The parent/carer BRIEF-2 Inhibit scale inquiries about the frequency of behaviours including being ‘fidgety’. An alternative explanation for these findings could be those children with poor motor skills ($\leq 16^{th}$ percentile) have poorer postural control and are more likely to engage in behaviours such as fidgeting. Whilst Michel et al. (2018), also found relationships between Inhibition and overall motor skills to differ for those with

DCD and TD peers, Alesi et al. (2019) and Pratt et al. (2014) did not find significant relationships in either group. When relationships were examined across children with a range of motor skills, significant relationships have been found in previous research (Rigoli et al., 2012; Stein et al., 2017) and are supported by the Study Two findings. This suggests that the limited number of significant relationships found to remain when groups were examined separately in Study Two, could be related to the limited range of scores.

10.4. Gross Motor and Ball Skills

Gross motor skills are organised differently in the MABC-2 and IDS-2 assessments used (see chapter six section 6.3.1.). In the IDS-2, there is an overall gross motor score based on performance on four components, balance, jumping, catching and throwing. However, the MABC-2 has a total balance score which is a composite from three balance tasks, with aiming and catching in a separate section. As the IDS-2 Gross Motor score incorporates aiming and catching, performance of aiming and catching from the MABC-2 Test is also considered here under gross motor skills.

10.4.1 Response Inhibition

Across the entire sample significant relationships were found between gross motor skills (including ball skills) and Response Inhibition with a verbal and motor response. When examined in each group individually, relationships between gross motor skills and Response Inhibition with a verbal response were no longer significant, and relationships between MABC-2 Aiming and Catching and measures of Response Inhibition were no longer significant. Significant relationships were found between the IDS-2 Gross Motor component and measures of Response Inhibition with a motor response (AdVIMI Motor error, RT and MT). These relationships remained significant when examined within the DCD group alone. This indicates that children with poorer gross motor skills were slower to react, less accurate and took longer to complete a Response Inhibition task which required a motor response. This is interesting because whilst the AdVIMI motor component requires a motor response, it is a fine motor response rather than a gross motor response that is needed. It could be argued that the correlations indicate a broader relationship with poorer overall motor skills, rather than gross motor skills specifically. Those likely to have the poorest gross motor skills are also likely to have the poorest overall motor performance. However, having poorer overall motor performance was not found to be significantly related to slower RT on the AdVIMI motor component. This suggests that gross motor skills specifically have a relationship to Response Inhibition performance which requires a motor response. A relationship was also found between MABC-2 Balance and the AdVIMI motor component RT for the entire sample and when examined in the TD group separately. Overall, these results support the argument that there is a specific relationship between Response Inhibition and gross motor skills (including ball skills).

10.4.2. Interference Control

A significant relationship was found between AdFlanker error rate and the IDS-2 Gross Motor component, however, when examined in DCD and TD groups separately no significant relationships were found between Interference Control error rate and any measure of gross motor performance. This could be due to the low error rate within both tasks. Relationships were found between the IDS-2 Gross Motor component and AdFlanker RT as well as the MABC-2 Balance and AdFlanker RT across the entire group, and within the DCD group separately. This indicates those with poorer gross motor skills were slower to react to the AdFlanker task. Ludyga et al. (2019), Maurer and Roebers, (2019), and Oberer et al. (2018), in a sample of children whose motor skills were not reported, all found a significant relationship between performance on a Flanker task and gross motor skills. However, studies have differed in methods of measurement (error rate or RT). van der Fels et al. (2019) found a significant relationship between RT increase between the congruent and incongruent condition of a Flanker task and gross motor skills in children aged eight to ten who's motor skills were not reported. However, when controlling for age, sex, school year and social economic status, this relationship was no longer significant.

It could be argued that the relationships between the AdFlanker RT and gross motor skills in this research is because of the shared motor demand of the tasks. However, the AdFlanker task required a minimal motor response (pressing a large button on a touch screen) and did not involve large body movements. Furthermore, relationships were also found between the IDS-2 Gross Motor component and AdAC completion time (which required a verbal response) across the entire sample and within the TD group separately, indicating that poorer gross motor skills were associated with longer AdAC completion time. These results provide evidence of a relationship between gross motor skills and measures of Interference control which require both a motor and verbal response.

10.4.3. Questionnaires

Relationships were also examined between Inhibition measured on the Inhibit scale of the parent/carer and teacher BRIEF-2 questionnaire and gross motor skills. Significant relationships were found between the BRIEF-2 parent/carer questionnaire Inhibit scale and the IDS-2 Gross Motor component, MABC-2 balance score and MABC-2 aiming and catching scores for the entire sample and in the TD group separately. This questionnaire asked about behaviours such as ‘getting out of control more than friends’, acting ‘wild and out of control’ and talking ‘at the wrong time’. Results suggest that a higher frequency of these behaviours at home is associated with poorer motor performance. When relationships were examined between the teacher BRIEF-2 questionnaire Inhibit scale, which included almost identical items to the parent/carer questionnaire, and gross motor measures, a significant negative correlation was also found with the IDS-2 Gross Motor component score. This is consistent with results from the parent/carer questionnaire. This indicates that poorer teacher reported Inhibition was also associated with poorer gross motor skills on this measure. This relationship was not found to remain significant when examined in each group separately. However, the small group sizes of children who had data from a teacher questionnaire (DCD = 16, TD = 13) may have affected the ability to detect relationships. Whilst relationships were not found to remain significant when examined in each group separately, Study One did not find a difference in teacher reported Inhibition between children with DCD and TD peers. This suggests that the relationship is more likely to be a meaningful reflection of an underlying relationship between teacher reported Inhibition and gross motor skills rather than a reflection of group differences. However, it is also possible that Study one did not find group differences on the teacher questionnaire Inhibit scale as it lacked the power to detect these differences. This is because, as previously stated, the sample of children who had data from a teacher questionnaire (DCD = 16, TD =

13) was smaller compared to children with a parent questionnaire (DCD = 25, TD = 25).

10.5. Fine Motor and Drawing Skills

The current research considers fine motor and drawing skills separately within the analysis, however, the majority of previous research has considered drawing skills as part of fine motor skills. They are discussed together here to facilitate comparison to previous literature.

Relationships between Inhibition and fine motor and drawing skills were assessed using tasks from two standardised batteries the MABC-2 Test and the IDS-2 (see chapter six section 6.3.1.). However, there were limitations to some of these measures, beyond the limited range of scores already discussed above (section 10.2). Chapter six (section 6.3.1.3.) detailed results which show that the IDS-2 Visuomotor Time score was not found to differentiate between those with DCD and TD peers, whereas the IDS-2 Visuomotor Quality score did differentiate between the groups. The IDS-2 Visuomotor Time score was also not found to significantly correlate to any measure of Inhibition whereas the IDS-2 Visuomotor Quality score and the MABC-2 Manual Dexterity did significantly correlate to measures of Inhibition. Therefore, it is unclear how sensitive the IDS-2 Visuomotor Time score is to differences in visuomotor skills.

10.5.1. Response Inhibition

Significant relationships were found between the AdVIMI motor error rate and MABC-2 Manual Dexterity across the entire sample and when investigated in the DCD group separately. A significant relationship was also found between the AdVIMI motor error rate and IDS-2 Visuomotor-Quality across the entire sample and when examined in TD and DCD groups separately. These relationships suggest that higher error rates in the AdVIMI motor task were associated with poorer fine motor and drawing skills when a motor response was required. It is possible that the relationships found between fine motor skills and Response Inhibition which require a motor response (making a fist, pointing a finger) are a reflection of the shared fine motor demands of the task. If a child has poorer fine motor and drawing skills, they will likely find it harder to make the response gestures accurately in comparison to TD peers and this would result in a higher error rate. However, an error was only measured in this task if the child performed the wrong action (e.g. a pointed finger rather than a fist), and not on the precision of the movement (e.g. if a child had two fingers pointed rather than one this was scored as correct). Furthermore, as relationships have also been found between gross motor skills and Response Inhibition, this provides wider support for an association between motor skills and Inhibition. Furthermore, a significant relationship was also found between AdVIMI verbal error rate and IDS-2 Fine Motor-Quality across the entire sample and in the DCD group separately, indicating that a higher error rate was associated with poorer quality drawing skills. This suggests relationships may not be fully explained by the shared fine motor demands of the task.

The majority of previous research which has investigated relationships between Response Inhibition and fine motor and drawing skills have also found significant relationships (Livesey et al., 2006; Rigoli et al., 2012; Simpson et al., 2019; Michel et al., 2018; Riggs et al., 2013; Stein et al., 2017). Collectively this suggests that the relationships found in Study Two indicate a direct association between fine motor and drawing skills and Response Inhibition rather than the shared fine motor demand of the tasks.

10.5.2. Interference Control

Significant relationships were found between the AdFlanker RT and IDS-2 Fine Motor Time as well as between the AdAC error rate and completion time and IDS-2 Fine Motor Time across the entire sample and when examined in children with DCD separately. This suggests that slower performance in fine motor tasks is associated with slower RT in an Interference Control task requiring a motor response, as well as more errors and slower completion in an Interference Control task requiring a verbal response. Together these results suggest that the relationships between the IDS-2 Fine Motor Time score and Interference Control is not exclusive to when a motor demand is needed but is also present when a verbal response is required. No relationships between MABC-2 and Interference Control measures were found to remain significant when examined in DCD and TD groups separately. This could be because the greater range of scores available on the IDS-2 Fine Motor Time resulted in greater sensitivity to detect relationships compared to the MABC-2 standard scores. Previous research did not find relationships between fine motor skills and Interference control when a task with a verbal response was used (adaptations of the Stroop task) (Alesi et al., 2019; Pratt et al., 2014). However, Alesi et al. (2019) and Pratt et al. (2014) used the MABC-2 Manual Dexterity component, which in Study Two also did not significantly relate to Interference Control with a verbal response. Michel et al. (2018) and Oberer et al. (2018) did find a relationship between fine motor skills and a Flanker task, which required a motor response.

Whilst relationships were found between measures of Interference Control which required a motor response and the IDS-2-Visuomotor - Quality measure across the entire sample, none of these relationships remained significant when examined in each group separately. Most previous research has considered drawing skills within the context of fine motor skills. However, Oberer et al. (2018) and Maurer and Roebers (2019) did consider relationships between Interference control and drawing skills separately from fine motor skills. Similarly to this study Oberer et al. (2018) and Maurer and Roebers, (2019) did not find a relationship between performance on the AdFlanker and the MABC-2 Manual Dexterity task 3, which is a drawing task. These results coupled with those from Study Two, suggest that drawing skills may not be related to Interference Control performance.

10.5.3. Questionnaires

Relationships were also examined between Inhibition measured on the Inhibit scale of the parent/carer and teacher BRIEF-2 questionnaire and fine motor and drawing skills. Whilst significant correlations were found between the parent/carer Inhibit scale and measures of fine motor and drawing skills none of these relationships remained significant when examined in each group separately. This suggests that the relationship found across the groups may be a product of the poorer parent/carer reported Inhibition skills of children with DCD found in Study One.

When relationships were examined between the teacher BRIEF-2 questionnaire Inhibit scale and fine motor and drawing measures, significant correlations were found with the MABC-2 Test Manual Dexterity component score (which includes fine motor and drawing tasks). This relationship indicates that poorer Inhibition at school is associated with poorer fine motor skills. However, this relationship was not found to remain significant when examined in each group separately. It is possible as mentioned previously (section 10.3.3.) that the smaller group size of children who had data from a teacher questionnaire (DCD = 16, TD = 13) may have affected the ability to detect relationships. Whilst the relationship was not found to remain significant when examined in each group separately, Study One did not find a difference in teacher reported Inhibition between those with DCD and TD peers. This suggests that this relationship is more likely to be a meaningful reflection of an underlying relationship between teacher reported Inhibition and fine motor and drawing skills rather than a reflection of group differences. As mentioned in section 10.3.3. the BRIEF-2 enquires about behaviour such as thinking ‘before doing’ and talking ‘at the wrong time’. Fine motor and drawing skills are required during many independent working school activities such as copying from the board or a textbook. It is possible that children who find these tasks challenging are more likely to ask their friends for help, get distracted because the task is difficult for them, or submit work that may appear rushed or not thought through. This could explain why poorer fine motor and drawing skills are associated with poorer teacher reported Inhibition. However, as relationships have also been found between fine motor and drawing skills and other areas of Inhibition, this could provide further evidence of a more direct association between Inhibition and fine motor and drawing skills.

10.6. Summary

Study Two was an exploratory investigation into relationships between Inhibition and motor skills in children with and without DCD, across a range of measures. Results show that all areas of motor skills investigated (overall motor skills, gross motor and ball skills, fine motor skills and drawing skills) significantly correlated with measures of Inhibition. Many of the relationships found when examined across children with and without DCD combined were also found to remain in at least one group when examined separately. This provides support that relationships were not just a reflection of group differences. The next chapter will provide a general discussion considering the findings of Study One and Two, limitations, practical implications, and suggestions for further work.

11. General Discussion

11.1. Introduction

The aim of this research was to investigate Executive Function skills, with a focus on Inhibition, in children with and without DCD. Executive Function skills are higher level cognitive skills used to achieve goal directed behaviour (Diamond, 2013). Executive Function difficulties have previously been reported as commonly co-occurring with the motor difficulties in children with DCD (Wilson et al., 2017). There has also been debate regarding whether Executive Function difficulties are potentially an underlying mechanism contributing to the motor difficulties seen in children with DCD (Blank et al., 2019). Executive Function difficulties have been noted in recent systematic reviews of DCD (Wilson et al., 2017; Wilson et al., 2013) and appear in the model of DCD outlined in the International Guidelines (Blank et al., 2019). Adolescents with DCD have also highlighted Executive Function difficulties as their main barrier to participation in academic, vocational, recreation and family life (O'Dea and O'Connell 2016). Therefore, it is important to understand when these difficulties emerge and their relationship to the motor skill difficulties. The majority of researchers agree that Executive Function has both Unity and Diversity (Miyake et al., 2000). This Unity and Diversity means that Executive Function is comprised of individual components which are distinct from each other but also share the same underlying features. The most commonly cited components are Working Memory, Mental Flexibility and Inhibition.

The research in this thesis focused on Inhibition, because it is relatively understudied in DCD in comparison to other components of Executive Function such as Working Memory (Alloway, 2007, 2011). Evidence from Miyake et al., (2000) also suggests that Inhibition may be what is common to all EF components. Inhibition has links to overall health and wellbeing, as well as being important for everyday life. A longitudinal study by Moffit et al. (2011) found that better Inhibition skills in children aged three to eleven years was associated with better physical and mental health, better educational attainment and reduced engagement in drug taking behaviours in adulthood. In everyday life, Inhibition is necessary for children to maintain focus in classroom tasks, sports and social conversations as well as to adapt initial plans for action based on new information. Poor Inhibition may impact on other aspects of behaviour such as calling out in class and rushing through work. As Inhibition difficulties are not immediately apparent, behavioural manifestations could be misinterpreted as intentional 'naughty' behaviour or disengagement which can potentially affect children's self-esteem and contribute to the increased internalising symptoms observed in children with DCD (Omer et al., 2019). There is evidence that children with DCD have lower self-esteem than both typically developing children and those with more severe physical disabilities such as cerebral palsy (Miyahara & Piek, 2006). It has been suggested that this may be because of a limited understanding of their difficulties from those around them compared to peers with more severe physical disabilities (Piek & Rigoli, 2015). There is debate regarding whether low self-esteem, depression and anxiety co-occur with DCD or if they are secondary consequences related to the lived experiences of those with DCD. Camden et al.'s (2015) best practice guidelines for the management of DCD include interventions aimed at the prevention of internalising symptoms and low self-esteem in children with DCD. They highlight the importance of families, communities and children themselves understanding the full profile of difficulties so that their behaviour can be better understood, and children can be better supported. Tamplain and Miller (2020) also emphasise that a comprehensive understanding of DCD is important for preventing internalising symptoms and low self-esteem.

Inhibition difficulties have also been suggested as a potential underlying mechanism for the motor difficulties in DCD. This is because the ability to focus on task relevant stimuli, and inhibit automatic responses, enable people to respond appropriately to task and environmental cues which are necessary for completing or mastering many motor activities. Navigating a busy environment, for example, requires the ability to maintain focus on task relevant information and adapt actions (such as stopping, or moving out of the way) based on changing environmental conditions. Inhibition is also important in adapting actions in sports and playground games based on continually changing environmental circumstances (e.g. a moving football) and therefore Inhibition difficulties could contribute to reduced mastery of and participation in these activities, limiting socialising and physical activity opportunities. Therefore, understanding the Inhibition skills of children with and without DCD can have important theoretical and practical implications.

Some previous research suggests that children with DCD have difficulties with Inhibition (e.g. Sartori et al., 2020; Thornton et al., 2018) however results are inconclusive, and no research has included a comprehensive assessment of Inhibition. As explained in earlier chapters, there are issues in comparing the results of previous research due to methodological differences and limitations such as; the variety of tasks used, the large age range of participants and many studies using the description of 'motor difficulties' for participants rather than confirming a clear diagnosis of DCD. Study One and Two in this research included a full diagnostic assessment and carefully matched samples. Study One is the first to have examined the Inhibition skills of children with DCD and TD peers in a comprehensive way. This included the use of adapted Interference Control and Response Inhibition tasks previously used in the literature, a standardised battery of Executive Function to measure Executive Function components working collaboratively; and parent/carer and teacher questionnaires that assess Executive Function and Inhibition in everyday life. Furthermore, the effect of response modality (motor vs. verbal) was also examined. Study Two provided a more thorough investigation of relationships between Inhibition and motor skills in children with and without DCD than has previously been undertaken.

Chapters eight and ten have considered the findings of Study One and Two in relation to the wider literature and limitations which are specific to each study. In this chapter the collective findings from Study One and Two are considered and the theoretical and practical implications of the work discussed. Limitations of the research and directions for future work are highlighted.

11.2. Summary of Findings

11.2.1. Study One

Study One found that children with DCD had poorer Inhibition skills compared to TD peers on a range of measures. In the experimental tasks the congruent condition was the control condition and the incongruent condition assessed Inhibition (Response Inhibition or Interference Control). In the AdVIMI motor task (assessing Response Inhibition) children with DCD were found to have significantly more errors and longer movement times (MT) for both the congruent and incongruent conditions. However, children with DCD were also found to have a significantly larger increase in error rate and MT between the conditions compared to TD peers. This provides evidence that children with DCD experienced greater difficulty with Response Inhibition with a motor response compared to TD peers. Children with DCD were also found to make significantly more errors in the incongruent condition of the AdVIMI verbal task (assessing

Response Inhibition with a verbal response), as well as longer completion times in the AdAC task incongruent condition (assessing Interference Control with a verbal response). No significant differences in error rate in the AdVIMI verbal task and completion time for the AdAC task were found in the congruent condition. Collectively these results provide evidence that children with DCD had poorer performance on Response Inhibition tasks which required a motor and a verbal response, and an Interference Control task which required a verbal response, compared to TD peers. Children with DCD were also found to have significantly slower RT on the congruent and incongruent conditions of the AdFlanker which is the Interference Control task with a motor response. However, no significant group differences in the increase in RT between conditions were found. This suggests that children with DCD did not have poorer performance on Interference Control which required a motor response.

In tasks from a standardised battery of Executive Function, children with DCD were found to have significant difficulties on two of the six measures which had Inhibition and Mental Flexibility demands (the Animal Colours task and the Divided Attention – Listing Animals task). This suggests that children with DCD have difficulties in tasks which do not isolate the Executive Function components but have a substantial Inhibition requirement. In standardised parent/carer and teacher questionnaires children with DCD were also reported to have poorer overall Executive Function skills affecting everyday life. Inhibition specific difficulties were also reported on the parent/carer questionnaire but not the teacher questionnaire. According to parent/carer ratings, 60% of the DCD group had overall scores and 16% had Inhibition scores that fell in a category considered to be at least potentially of clinical relevance.

Analyses of the results on all measures (excluding the teacher questionnaire) were repeated after removing the eight children with DCD who had diagnosed co-occurring Attention Deficit Hyperactivity Disorder (ADHD) and/or Autism Spectrum Condition (ASC) and their eight age and sex matched TD controls. This was to assess whether the inclusion of children with these conditions could explain the group differences found in Study One. Removing children with co-occurring conditions did not substantially alter the findings (see Appendix L). These results indicate that the inclusion of children with co-occurring conditions cannot explain the group differences found in Study One.

In addition to the group analyses, individual results were also considered across all measures of Inhibition (excluding the teacher questionnaire). Children with DCD were found to have more ‘below average’ scores compared to TD peers. However, individual differences in the profile of performance across Inhibition measures were also evident in the DCD group. Performance profiles of the entire sample show that 56% of the children with DCD had scores which were ‘below average’ for over half of the Executive Function measures used, over 90% of children with DCD had ’below average’ scores for at least a quarter of the items, compared to only 16% of TD children. This provides further evidence that children with DCD had poorer Executive Function performance, with a focus on Inhibition, but that there is some individual variation in the nature/expression of their difficulties.

Results from the experimental tasks were also examined in a subsample of children with DCD with less severe motor difficulties (9^{th} – 16^{th} percentile) and age and sex matched TD peers. In this subsample children with DCD were found to have a significantly higher error rate on the Response Inhibition task which required a verbal response, however, no other significant group differences were found. This suggests that the individual differences in Inhibition found in Study One, could be related to the severity and profile of motor skills in the DCD group.

11.2.2. Study Two

In Study Two, when correlations were examined across the entire sample (n = 50), there were significant relationships between at least one aspect of Inhibition and all areas of motor skills assessed (overall motor skills, gross motor, fine motor, and drawing skills). However, results differed across domains and measurements used. In all cases poorer Inhibition skills were associated with poorer motor performance. Many of these relationships remained significant when examined separately in at least one of the groups, however, groups differed in which relationships remained significant.

In the DCD group significant relationships were found between:

- Overall motor skills and both Response Inhibition and Interference Control tasks which required a motor response.
- Gross motor skills and both Response Inhibition and Interference control tasks which required a motor response.

- Fine Motor skills and both Response Inhibition and Interference Control tasks which required a motor and verbal response.
- Drawing skills and a Response Inhibition task which required a motor response.

In the TD group, significant relationships were found between:

- Overall motor skills and parent/carer reported Inhibition skills.
- Gross motor skills and a Response Inhibition task which required a motor response, an Interference Control task which required a verbal response and parent/carer reported Inhibition skills.
- Drawing skills and a Response Inhibition task which required a motor response.

These results suggest that there is a relationship between motor and Inhibition skills.

11.3. Methodological, Design and Analysis Challenges

The study of neurodevelopmental disorders is complex and research in this field presents many challenges. In this section some of the main methodological, design and analysis challenges are outlined. It is important to acknowledge both the strengths and the limitations of Study One and Two. Some methodological issues pertaining to Study Two have previously been highlighted in chapter 10 (section 10.2.). This section discusses the participants, potential confounding variables, the Executive Function and motor skills measures, study design and data analysis techniques used.

11.3.1 Participants

As noted in earlier chapters, one of the challenges in drawing conclusions about DCD from previous research has been the variety of selection methods used for participants. Some studies only partially apply diagnostic criteria and others include a mix of participants. One of the strengths of this research was the thorough assessment of children for the DCD group, in line with the International Guidelines for DCD (Blank et al., 2019) and the DSM-5 (American Psychiatric Association, 2013). The findings therefore make an important contribution in building on the evidence base using a robust sample of participants with DCD. It should be noted that the rigour of this approach is somewhat offset by the time taken and challenges of recruiting sufficient numbers. However, the sample size in this research was larger than that used in previous studies investigating EF in DCD and was adequately powered to address the group differences. The recruitment methods also ensured that findings from Study One and Two could be generalised to other children with DCD. A further strength was the tight matching of the two groups, which limited the effect that age or sex could have on the results. Whilst it was not possible to assess the results of the full IDS-2 intelligence component, as standard scores were not available, groups were also found to match on the British Picture Vocabulary Scale 3rd Edition which has been found to correlate highly with verbal IQ (Glenn & Cunningham, 2005). The age range (six to ten years) was also a strength of this research as it was narrower than the majority of previous research which has investigated differences in Inhibition skills between children with and without DCD (Mandich et al., 2003; Piek et al., 2004; Pratt et al., 2014; Querne et al., 2008; Rahimi-Golkhandan et al., 2014, 2016; Ruddock et al., 2015; Thornton et al., 2018). Therefore, compared to previous research this limited the effect that developmental differences could have on results. However, as discussed in chapter 3 section 3.3. there is currently no consensus on the factor structure of Executive Function in young children. Therefore, it is possible that the same task may have tapped into differing Executive Function components. There is evidence that the structure of Executive Function components change with age (Hughes et al., 2010; Miyake et al., 2000) and that relationships between Executive Function and motor skills may also change with age (Stuhr et al., 2020). Chapter 3 section 3.3.1. also outlines evidence of differing developmental trajectories for Response Inhibition and Interference Control. Whilst there is evidence that both are in the developing stages in children aged six to ten years (Brocki & Bohlin, 2004; Brydges et al., 2013; Huizinga et al., 2006), the detail of this development is unknown. Therefore, further research with even narrower age ranges would be recommended, to further limit the impact of age when examining group differences.

11.3.2. Potential Confounding Variables

Another challenge in this field of work is the number of potential confounding variables such as levels of hyperactivity and inattention and diagnosed conditions co-occurring with DCD. To address these issues, in Study One, ANCOVA was used to take account of the higher hyperactivity and inattention SDQ scores in the DCD group (See chapter seven section 7.6.2 and Appendix B). Out of the tasks that were eligible for the use of ANCOVA, only group differences on the Global Executive Function Composite score from the BRIEF-2 parent questionnaire remained significant. This suggests that higher hyperactivity and inattention in the DCD group could explain the group differences in Executive Function skills with a focus on Inhibition. The SDQ has UK bandings based on a community sample. The DCD group mean fell in the 'slightly raised' category, and 19/25 (76%) children with DCD had scores that were 'slightly raised', 'high' or 'very high.' Children with DCD have been widely reported to have higher hyperactivity and inattention scores on the SDQ (Crane et al., 2017). This suggests that the higher hyperactivity and inattention score is not independent of group membership and therefore it may not be appropriate to partial out its effects. Furthermore, as mentioned in chapter 6 section 6.5.1., questions on the hyperactivity and inattention scale of the SDQ (e.g. 'constantly fidgeting or squirming', 'concentration wonders', 'doesn't think things through before acting') are similar to those on the Inhibit scale of the BRIEF-2 (e.g. 'is fidgety', 'talks at wrong time', 'is impulsive'). Therefore, hyperactivity and inattention as measured on the SDQ may measure aspects of Inhibition in everyday life. This could explain why controlling for hyperactivity and inattention may have produced non-significant group differences on many of the variables. It also suggests that controlling for hyperactivity and inattention on the SDQ may not be appropriate.

The hyperactivity and inattention scale is often used in research as a proxy measure of ADHD symptomology (Hall et al., 2019). However, this scale is not sufficient to identify co-occurring ADHD (Hall et al., 2019). A further strength of this research was the inclusion of children with diagnoses of co-occurring conditions (ASC and ADHD) in the DCD group as this is representative of a clinical sample of children with DCD. This also enabled results of Study One to be analysed excluding the children with co-occurring conditions and their TD age and sex matched controls to examine the effect their inclusion may have had on the results. This analysis showed similar results to the full sample analysis, suggesting that their inclusion cannot explain the group differences found between those with DCD and TD peers in Study One.

Cremone-Caira et al. (2020) found that children aged seven to eleven years, with a dual diagnosis of ASC and ADHD had a different profile of Inhibition performance compared to children with a singular diagnosis of ASC or ADHD. The group with a dual diagnosis of ASC and ADHD, for example, took longer to inhibit responses in a stop signal task compared to peers with a singular diagnosis, whereas children with a singular diagnosis of ASC performed more poorly on an Interference Control task (Stroop task) compared to those with a dual diagnosis of ASC and ADHD. Cremone-Caira et al.'s (2020) research provides evidence for unique patterns of Inhibition skills for those with multiple developmental disorders. This is further supported by Thornton et al. (2018) who found, using functional magnetic resonance imaging, differing patterns of brain activation using a Response Inhibition task (a Go/Nogo task) for children with dual diagnosed ASC and ADHD compared to TD peers. They did not find evidence of differing activation patterns for children with DCD or ADHD alone, however, their sample size for the DCD group was very small (n = 9), limiting the power to detect an effect. Future research could consider, in greater detail, the impact of dual diagnosis on children with DCD across a range of Inhibition measures assessing both Response Inhibition and Interference Control. Furthermore, as motor difficulties are well documented in other developmental conditions (Kirby et al., 2014), using tasks such as the AdVIMI, that consider the impact of response modality on performance would also be helpful in furthering the understanding of Inhibition in other developmental disorders.

11.3.3. Measures

11.3.3.1. Executive Function Measures. The multi-faceted and complex nature of Executive Function presents many challenges to measurement. The range of Executive Function measures used was a strength of this research as it enabled a comprehensive assessment of Inhibition within the context of the Unity and Diversity Model. Using experimental tasks, a standardised battery, as well as parent/carer and teacher questionnaires enabled the assessment of Inhibition within a highly controlled environment as well as within everyday life. The experimental tasks were a strength of this research. With most measures based on tasks previously used in DCD research, the findings help to build the evidence base in a systematic way. The tasks were carefully selected to assess the impact of response modality on performance and to assess specific domains of Inhibition. The AdVIMI was an adaptation of a task previously used with children with DCD. This was to directly build on previous work whilst increasing the sensitivity of the measure. This adaptation improved the ability to assess the influence of response modality on results by limiting the influence of external variables. For example, in the VIMI motor task the stimuli were visual, and in the VIMI verbal task were auditory; in the AdVIMI the stimuli for both the motor and verbal tasks were visual. However, for the Interference Control tasks, differences in measurement (e.g. completion time vs. RT) affected the ability to directly compare performance across these different response modalities.

All of the experimental tasks used in this thesis were specifically designed or chosen to be entertaining to children and to limit the influence of other variables on performance, such as a lack of attention to the task. However, balancing the engagement of the child and the sensitivity of the task is challenging and may have resulted in the low error rate in some of the tasks. Whilst using fewer trials in tasks, compared to adult versions, helps reduce the impact of confounding variables, Rouder et al. (2019) suggest that having fewer trials effects the reliability of results. They highlight that performance on Inhibition measures is subject to large measurement error and variance across trials and advocate for the use of a large number of trials to minimise this error. However, this is not practical with young children. Therefore, it is possible that measurement error could explain some of the variance in the performance of children on individual tasks.

A fundamental difficulty when measuring Executive Function is the issue of task impurity (Burgess, 1997). Executive Function tasks, even when aiming to isolate individual components, rely on a range of other processes not directly under investigation such as the motor or language skills needed to respond to or understand task instructions. This can complicate the interpretation of the findings. This issue has impacted the interpretation of previous research (outlined in chapter 4 and 5) which often used only a single task to assess Inhibition in children with DCD and relationships with motor skills. Similarly this research, whilst building on the range of tasks used in previous research, still used only one measure for each Inhibition construct (Response Inhibition and Interference Control) separated by response modality (verbal, motor). Therefore, it was not possible to consider the potential influence of task impurity on the results. Furthermore, Chapter 3 section 3.3. highlighted that the development of Executive Function skills has high individual variance with development occurring in spurts and that the structure of Executive Function has been found to differ with age. Inclusion of a range of tasks to measure Inhibition, may help to address the potential issues of task impurity and developmental sensitivity. Therefore future research could consider using several tasks for each construct (e.g. the Response Inhibition tasks with a motor response) and use latent variable analysis to account for task impurity difficulties. It was important for this research to build on previous research by using tasks/adaptations of tasks which had previously been used with children with DCD. However future research should also try to create tasks that alter only the response modality (verbal vs. motor) to limit the influence that other task demands could have on results. In clinical settings an understanding of measurement error is important and decision making should take this into account. Many standardised tests, for example, provide details of Standard Error of Measurement (SEM) and confidence intervals. However, this is more difficult to apply in research and experimental work.

This research was designed to align with Nigg's (2000) Taxonomy of Inhibition which divides Inhibition into Response Inhibition and Interference Control. As outlined in chapter three (section 3.2.1), it is widely acknowledged that there is a distinction between Response Inhibition and Interference Control (Laloi et al., 2017) and research has confirmed differing patterns of brain activation for these two components (Brydges et al., 2012; 2013). However, Rouder et al. (2019) state that it remains unknown if Response Inhibition and Interference Control can be clearly distinguished. They argue that evidence supporting this theory could be the result of large measurement error inherent in the examination of Executive Function. In this research the pattern of findings for the two types of Inhibition were generally similar. However, these studies were not designed to explore distinctions between Response Inhibition and Interference Control and this is an area that needs to be explored in future work.

11.3.3.2. Motor Measures. The different motor measures used in previous research help to provide a comprehensive understanding of motor performance difficulties. The range of motor measures used was a strength of this research. These measured different aspects of motor performance including gross motor (and ball skills), fine motor and drawing skills, with some separate measures for time and quality. However, the IDS-2 was still under development and standard scores were not available at the time of writing. Furthermore, some of the measures had ceiling effects which affected the ability to detect relationships in Study Two, particularly when correlations were considered in each group separately. The range of scores achieved also differed between the groups. This affects the confidence with which relationships between Inhibition and motor skills can be compared between the groups in Study Two. This research also included two children who completed age band one of the MABC-2 Test and therefore completed different tasks to the other children. Further research which uses the MABC-2 Test should consider using a narrower age range of children which would negate the need to cross over age bands. A challenge for future research is to include measures that have sensitivity at both the bottom and top end of the scale, giving a greater range of scores across groups. This has previously been raised as a difficulty in this area (Holmes, 2009).

11.3.4. Study design and Data Analysis. This research provided a comprehensive examination of group differences in Inhibition and relationships between Inhibition and motor skills. The group comparison findings build on previous work on Executive Functions in DCD and extend this to consider Inhibition in particular. Two further aspects of the study design and analysis enabled further exploration of the relationship between Executive Function and motor skill. Firstly, an examination of individual profiles showed considerable variation in performance on the Executive Function and Inhibition measures, but it was clear that every child in the DCD group showed poor performance in at least some aspects of Inhibition. Secondly, in a sub-sample of those with less severe motor impairments, Inhibition difficulties were not evident (except for one measure) when compared with matched controls. This suggests that the EF difficulties are related to greater motor impairment in the DCD group.

Various other sub analyses have also been undertaken to better understand the Inhibition difficulties in DCD. These include analyses to examine the effect of variables such as ANOVA controlling for higher hyperactivity and inattention in the DCD group (Appendix B) and the exclusion of children with co-occurring conditions and their age and gender matched controls (see Appendix L). Study One and Two did not use statistical corrections but did provide full details of p values and 95% confidence intervals in Appendix N and R. The rationale for not using statistical corrections in analyses was outlined in chapter six (section 6.5.) and further explanation is provided in Appendix M. Whilst this was reasoned to be appropriate for both Study One and Two, it is important to reiterate the inflated type one error risk which occurs when running multiple analyses on the same data set.

Study Two was of an exploratory nature, due to the limited previous research and therefore no specific predictions were made. Therefore, future research is needed using a different sample of children, to confirm the specific pattern of relationships which were found. However, whilst Study Two provided valuable evidence of relationships between motor skills and Inhibition, future research should consider the usefulness of running further correlational analyses, as this is limited in application to theory and practice as causation cannot be confirmed. Future research could instead consider if the Inhibition skills of children with DCD improve following an intervention aimed at improving motor skills. It would also be interesting to consider whether relationships between motor and Inhibition skills are consistent across other developmental disorders such as ADHD and ASC and those with multiple diagnoses. A further consideration, is whether better Executive Function or Inhibition skills could be a protective factor in those at risk for DCD who go on to develop typical motor skills. Another important point is that some of the predictions for Study One were null predictions. These were based on previous research which had varied results but on balance suggested that a group difference in Study One would not be expected. These analyses were important to run due to the conflicting nature of previous results. However, it is important to acknowledge that there are issues with null predictions as it is impossible to prove the absence of a group difference or relationship.

11.4. Theoretical Implications

There are several theoretical implications which arise from the findings of Study One and Two. These will be considered in relation to the frameworks outlined in chapter two, section 2.4.1.

11.4.1. Automatisation Deficits and Limited Attention Capacity

Study One found that children with DCD had significantly poorer performance on measures of Response Inhibition and Interference Control when a motor and a verbal response was required. This finding suggests that the skill automatisation deficits and limited attention capacity (outlined in chapter two section 2.4.1.1.) cannot singularly account for the motor difficulties central to DCD. This is because it is likely that deficits in Inhibition and other Executive Function components may also negatively impact performance. Poorer performance on Inhibition measures with a verbal response also suggests that the skill automatisation deficits and the limited attention hypothesis cannot fully explain Inhibition difficulties in children with DCD. However, poor skill automatisation and limited attention capacity could have resulted in the higher error rates observed for children with DCD in the Response Inhibition task when a motor response was required compared to when a verbal response was required. This suggests that performance of a motor task with Response Inhibition requirements could be particularly challenging for those with DCD.

However, whilst the Response Inhibition task with a motor response was found to produce significantly more errors and faster RTs than when a verbal response was required, the effect of response modality did not significantly differ between the groups. It is possible that a motor demand with greater complexity may elicit a significant difference in the effect of response modality between the groups. Furthermore, the effect of response modality was not able to be directly investigated for the Interference Control tasks due to differing measurements used across the tasks.

In the Response Inhibition motor task children with DCD were found to make significantly more errors in the incongruent condition than in the congruent condition. However, in the Interference Control motor task children with DCD were not found to make significantly more errors in the incongruent condition compared to the congruent condition. Whilst this could be because the tasks assessed different Inhibition components, the difference in results could also be explained by differences in the complexity of the motor demand required for the two tasks. The motor response of pressing a button in Interference Control tasks is arguably less complex than making a fist and pointing a finger which was the required response in the motor Response Inhibition task. Future research should aim to consider this further by examining the effect of motor complexity on Inhibition performance for children with DCD in both Response Inhibition and Interference Control tasks using comparable response modalities.

11.4.2. Executive Function as an Underlying Mechanism for Motor Difficulties in DCD

Chapter two (section 2.4.1.2) outlined the theory that Executive Function difficulties may be an underlying mechanism for DCD. Alternatively, the Executive Function difficulties reported in children with DCD may just be a co-occurring difficulty. Several aspects of the findings of this research tentatively support the former interpretation. Study One found that no child with DCD had all their Executive Function scores fall within the typical range and 90% had at least a quarter of all Executive Function scores fall one SD below the TD mean, and Study Two found relationships between all areas of motor performance and Inhibition. These results suggest that Executive Function skills are not a co-occurring difficulty for children with DCD but are instead related to the motor skill difficulties experienced. This is further supported by findings from Study One that in a subsample of children with DCD who had less severe motor difficulties fewer significant group differences were found on the Inhibition experimental tasks. This suggests that less severe motor difficulties in children with DCD could be explained by better Inhibition skills. In Study Two, 28% (13/47) of the significant relationships between motor skills and Inhibition found across the entire sample remained significant when examined in the DCD group separately and significant relationships were found between Inhibition and all areas (overall motor, gross motor, fine motor and drawing skill) for the DCD group. This suggests that Inhibition is related to all aspects of motor performance for children with DCD.

In future research it would be interesting to consider in more detail the within group Executive Function differences in children with DCD. Performance between those with DCD who have less severe motor difficulties could be directly compared to those who have more significant motor impairments. This could further the understanding of the interconnection of Executive Function and motor skills in children with DCD. Including a TD group in this research could also provide further insight regarding whether there is a linear relationship between motor and Executive Function skills or whether there is a threshold level of Executive Function skills, below which motor skills are impacted. In the current research, 11% (5/47) of the significant relationships between motor skills and Inhibition remained significant when examined in the TD group separately. Although this supports some connection between Executive Function and motor skills, restricted ranges of scores (as previously discussed in 11.3.3.2.) limits the interpretation of other non-significant results across the measures.

This thesis has focused on poor Executive Function skills in the DCD group and examined relationships between Inhibition and motor skills specifically. As motor development is understood to be central to development in other domains (Leonard, 2016) it could be considered that poorer motor skills may lead to poorer Inhibition. However poorer Inhibition skills are also likely to impact on the development of motor skills, so the relationship may be bi-directional. The complex issue of the nature of relationships between Executive Function and disordered development is a common consideration in research with many neurodevelopmental disorders (e.g. Developmental Language Disorder, ADHD, ASC) (Pauls & Archibald, 2016; Johnson, 2012) and needs further investigation.

Johnson (2012) argues that, rather than poor Executive Function skills impeding performance for those with neurodevelopmental disorders, good Executive Function skills may drive development in other domains for those with typical development. This view also aligns with what Iverson (2010) has called 'normally participatory'. That is, in typical development, Executive Function is usually a key player/participant in the process of motor development (or vice versa). It seems that there is a relationship between the two but it is complex and multifaceted, as found in other related aspects of development, such as motor and language skills (Iverson, 2010).

11.4.3. Biological Mechanisms

The group differences in Inhibition skills found in Study One, and the relationships found between Inhibition and motor skills in Study Two strongly support shared biological mechanisms in DCD. Biological mechanisms at a neuroanatomical level were described in chapter two (Section 2.4.1.3) as a potential underlying mechanism for DCD. They have also been considered as a potential explanation for relationships found between Inhibition and motor skills (van der Fels et al., 2019). The coactivation of regions responsible for Inhibition and motor behaviours, including the cerebellum, dorsolateral prefrontal cortex and basal ganglia (Diamond, 2000), suggests that the output of these neural circuits could influence both Inhibition and motor skills. As outlined in Chapter 2 (section 2.4.1.) there is evidence to suggest that, compared to TD peers, children with DCD demonstrate different patterns of brain activation in key areas (Zwicker et al., 2011). Children with DCD have been found to have differences in the activation of neural networks associated with both Executive Function and motor skills such as the cerebellum, prefrontal cortex, and striatum (Deng et al., 2014). This suggests that they may also have differences in the associations between motor and Inhibition skills compared to typically developing children with more mature Executive Function and motor skills, helping to explain the results from Study Two. However, these findings are not universal. Thornton et al. (2018) found differing brain activation patterns for children with a dual diagnosis of DCD and ADHD compared to TD peers but did not find a difference between those with DCD or ADHD alone compared to TD peers. Thornton et al.'s (2018) results could potentially be explained by the smaller sample sizes of children with DCD compared to those with a dual diagnosis (DCD = 9; DCD/ADHD = 18). Thornton et al. (2018) also suggest that their results may differ from previous research due to the lack of rigorous screening for co-occurring conditions in previous research, subtle differences in task design, different imaging acquisition parameters, as well as the heterogenous sample sizes, large age ranges and differing inclusion criteria used across the literature. Further research addressing these limitations would be needed to assess whether the results of Study One and the differing relationships found between those with and without DCD in Study Two might be explained by differing brain activation patterns between children with and without DCD.

In Study Two more relationships were found to remain significant when examined in the DCD group compared to the TD group. Stronger associations between developmental domains such as fine and gross motor skills and theory of mind, have been found in children with the neurodevelopmental disorder ASC (Dyck et al., 2006), which frequently co-occurs with DCD. This could suggest that cognitive and motor skills have a stronger association in developmental disorders compared to TD peers. However, the differences in relationships between children with DCD and TD peers need to be interpreted with caution due to limitations in measurement discussed in section 11.3.

Further potential support for this theory of overlapping neural networks implicating both motor and Executive Function skills comes from children with motor disorders associated with known neurological deficits. For example, studies on children with Cerebral Palsy (Bottcher et al., 2009) and children with Spina Bifida Myelomenginocele (Rose et al., 2007) have found Executive Function deficits accompanying the motor difficulties. The presence of motor and Executive Function difficulties in children with conditions with known neurological involvement suggest that differences in neural activation patterns in children with DCD may explain the group differences found in Study One. It also provides support that the relationships between Inhibition and motor skills found in Study Two could be the result of overlapping neural systems.

Further research is needed to confirm this theory of overlapping neural mechanisms using brain imaging research which utilises tasks such as those used in this research which control for response modality. Longitudinal research would help to show the development of neural pathways and activation patterns in children with DCD and enable comparison both with age-matched and younger controls. This may indicate whether neurological development is delayed or follows a different pathway in DCD (see chapter 10 section 10.1.).

11.4.4. Behavioural Explanations

Findings from Study One and Two could also be explained by motor behaviour and practice/participation. Motor and Inhibition skills are both required for and developed through engaging in activities such as dynamic sports. This relates to the theory of embodied cognition (Simpson et al., 2019), which posits that the physical interaction of a persons' body in the world has a constitutive role in the development of cognitive abilities such as Inhibition (Marshall, 2016). Therefore, engagement in activities such as football and tennis improve motor and Executive Function skills such as Inhibition simultaneously. Children with DCD are reported to participate in fewer sporting activities and have higher rates of sedentary behaviour in comparison to TD peers (Steenbergen et al., 2020). This could explain why the Inhibition skills of children with DCD are poorer than their TD peers. This could also explain the relationship found between Inhibition and motor skills. This is because, as outlined in chapter 5 section 5.1, motor and Executive Function skill have been considered to have a dynamic interaction (Adolph & Hoch, 2019). When children engage in sporting activities, they develop their motor skills. This enables them to engage in motor tasks with greater complexity which require, and therefore improve, Inhibition skills (e.g. playing football, building toy models). Response Inhibition is required when playing football to quickly adapt movements based on changing environments (van der Fels et al., 2019), it is also required when building toy models, to carefully read the instructions prior to acting. Interference Control is also required to ignore distracting information in many motor tasks, for example when shooting a basketball into a hoop during a basketball game. It is possible that those who have better motor skills engage in more advanced sporting activities which also improves their Inhibition and that those with poorer motor skills do not engage in these activities and therefore do not benefit from improved Inhibition skills. This could explain the relationship found between motor and Inhibition skills.

11.4.5. Dynamic Systems Theory and The Canadian Model of Occupational Performance and Engagement

Findings from the individual profile analysis in Study One make an important contribution to recognising and understanding individual differences in DCD. Whilst all children with DCD experienced some Executive Function difficulty (a score falling one SD below the TD mean) there was individual variability in the extent and pattern of these difficulties and the effects on everyday life at home and school. This individual variability needs to be recognised in theoretical explanations of DCD. Due to this individual variability and the inherent challenges with accurately measuring Executive Function skills throughout development, Executive Function difficulties should not be considered a core defining symptom at a single point in time for children with DCD. Rather Executive Function should be incorporated into a comprehensive assessment of performance challenges, and re-assessment conducted as needed throughout development.

The exact mechanism behind the Executive Function difficulties of children with DCD found in Study One and the association between Inhibition and motor skills found in Study Two is currently unexplained. The Dynamic Systems Theory (see chapter two section 2.4.) emphasises the bidirectionality of interactions with executive and motor domains (Smith & Thelen, 2003). This theory views development in one area as the product of interacting domains in a complex dynamic system. This suggests that rather than one causal mechanism for the motor difficulties in DCD (e.g. Executive Function or Inhibition specific difficulties), that there is instead an interdependence between the systems. This potentially explains the relationship between Inhibition and motor skills found in Study Two, as well as the in-group variation in Executive Function skills observed in the DCD group in Study One. It also highlights the importance of considering performance, both in research and clinical practice, within a model that conceptualises this dynamic interaction. A good example of this is the Canadian Model of Occupational Performance and Engagement (CMOP-E) (Townsend & Polatajko, 2007).

The CMOP-E (Townsend & Polatajko, 2007) described in chapter two (section 2.4.) is an Occupational Therapy model. This model conceptualises how activity performance and participation is the result of dynamic interaction between the person, the occupation (task or activity), and the environment. The in-group variation in Study One, for example, could be influenced by parenting and environmental factors. Luo et al. (2007) used data from a large scale American national database on public and private kindergarten programmes which included 244 East Asian American children and 9815 European American children. They found that East Asian American children showed more advanced fine motor skills and mathematical ability compared to European American children, when variables such as age and social economic status were accounted for. Luo et al.

(2007) argue that the most likely explanation for these findings is differences in parenting. This suggests that environmental factors, such as parenting practices could also influence Inhibition, motor development, and the relationships between the two. As outlined in 11.4.4 those with better motor skills may be more likely to engage in sports that simultaneously develop their motor and Inhibition skills. This highlights the importance of considering the interdependence of not only different performance domains such as motor and Inhibition skills but also how these are influenced by the environment.

11.4.6. Inhibition and Response Modality

Previous work has considered whether Inhibition of motor responses differs from Inhibition of verbal responses (Messer et al., 2018). Whilst Study One and Two did not aim to explicitly address this, children with DCD were predicted to perform differently for tasks with a motor response compared to a verbal response (see chapter 4 sections 4.8.1. and 4.8.2.). The effect of response modality was also directly examined for the Response Inhibition AdVIMI task in Study One (section 7.3.1.3). This analysis found a significant effect of response modality for error rate and RT on Response Inhibition performance, with children making more errors but having faster RT when a motor response was required. However, it is not possible to determine if this was because of a difference inherent in the verbal and motor Inhibition responses or if this was related to differences in other task demands such as the difficulty of the task (i.e. saying the word ‘doll’ is potentially easier than pointing a finger). Whilst children with DCD were found to have poorer performance both when a motor and verbal response was required for Response Inhibition, in the Interference Control tasks differences between the groups were arguably only found when a verbal response was required. This is because as stated in section 11.2.1. when a motor response was required, significant differences were found in the congruent and incongruent conditions and children with DCD were not found to have a significantly larger increase in RT between the conditions. It is possible that the difference between the groups for children with DCD when a verbal task is required is related to the reported increased rates of language difficulties for children with DCD (chapter 2 section 2.6.3.). However, this was not examined in detail in this research. Further research should continue to examine if there are conceptual differences between Inhibition of motor or verbal responses, and the potential impact of this on children with DCD. This research would benefit from including a more extensive examination into language skills.

11.5. Practical Implications

A number of practical implications arise from Study One and Two relating to the measurement and assessment of Inhibition and intervention for children with DCD.

11.5.1. Measurement and Assessment

Given the findings from Study One, children with DCD should be routinely assessed for Executive Function and Inhibition specific difficulties. The individual differences reported in Study One suggest that assessing performance across a range of measures may be more accurate than relying on the results of a single measure. Individual differences on performance-based tasks of Executive Function and Inhibition could be related to several external variables.

It would be beneficial if, following examination of the reliability of the results, the AdVIMI was made available through open access for use in future research. It could be used to assess Inhibition and the effect of response modality in other developmental conditions such as ASC and ADHD, in which motor difficulties are widely reported (Kadesjo & Gillberg, 1998; Green et al., 2009). However, it is important to acknowledge that experimental tasks alone can be influenced by measurement challenges such as task impurity (see 11.3.3.1.). Whilst the experimental tasks used in this research were sufficient to detect group differences, a potential solution to these challenges when considering performance at an individual level, for clinical reasons for example, could be the use of dynamic performance assessment such as Dynamic Performance Analysis (DPA).

The DPA method of assessment provides a framework to guide task observations to assess when performance breaks down and how to test solutions. An observable Response Inhibition difficulty when tying shoelaces, for example, could be making the same procedural mistake repeatedly because it has become automatic. DPA guides the assessor in performance analysis and makes this approach more rigorous compared to informal observation (Polatajko et al., 2000). DPA is an integral feature of the Cognitive Orientation to Occupational Performance (CO-OP) intervention (discussed previously in chapter 2 section 2.8.1.) and has been used as part of this intervention approach both clinically and in research settings. However, DPA is very time consuming and may not be practical in settings such as the classroom.

Standardised batteries are also useful for the assessment of Executive Function. These assessments enable performance to be observed in a controlled environment and compared against normative data. This can prevent the over interpretation of results or behaviour. Standardised assessments also provide information on reliability estimates and confidence intervals which (as discussed in section 11.3.3.1.) are necessary for accurate interpretation of performance on Executive Function assessments in clinical settings. The IDS-2 is a standardised battery which includes Executive Function which is undergoing standardisation in the UK at the time of writing. The IDS-2, unlike experimental tasks, does not aim to assess Executive Function components in isolation. However, it does enable greater experimental control and easier comparisons of performance across participants compared to DPA.

This research has also shown that alongside performance-based assessments, questionnaires are also useful in gaining a full understanding of children's performance abilities in everyday life. The difference noted between parent/carer and teacher reports in Study One highlights the importance of collecting perspectives from both home and school when assessing Executive Function in everyday life. Collecting both parent/carer and teacher perspectives increases the ecological validity of the results (Howuen et al., 2017) and provides a fuller understanding of the child's abilities across multiple settings. Differences between the outcomes of the questionnaire from different informants/settings may suggest environmental influences that may support or hinder performance.

11.5.2. Intervention

One of the purposes of identifying difficulties in children with DCD is to provide appropriate intervention. The aim of this intervention is to limit the impact difficulties have on participation and performance satisfaction in the areas of CMOP-E: self-care, productivity, and leisure. Given the findings from Study One, children with DCD should receive interventions that support their Executive Function and Inhibition difficulties as well as their difficulties with motor skills. Using the CMOP-E as a guide, interventions can adapt tasks and environments to limit the impact that difficulties have on participation, as well as develop the skills of the person to facilitate participation. Task and/or environmental adaptations include the use of compensatory strategies such as using lists or having extra time that enable children to complete tasks independently. Results of Study One add to the understanding of the profile of difficulties that children with DCD are likely to experience. Raising awareness of the range of difficulties children with DCD are likely to experience, including those found in Study One, is an important environmental intervention which could reduce the likelihood of children developing low self-esteem and internalising behaviours (Camden et al., 2015; Tamplain & Miller, 2020).

Study One found that children with DCD have poorer Executive Function skills. Interventions at the level of the 'person in CMOP-E to address this should utilise 'top-down' approaches which employ explicit teaching or guided problem solving to achieve task performance, rather than 'bottom-up' approaches which develop underlying skills (Blank et al., 2019). Whilst research in typically developing populations and those with ADHD suggests Executive Function and Inhibition specific training can improve performance (Diamond & Lee, 2011; Korpa et al., 2020), there is little evidence of transfer to non-trained tasks (Diamond & Lee 2011; Thorell et al., 2009).

Study Two found a relationship between Inhibition and motor skills which could suggest that interventions that aim to improve one of these domains may improve the other. Interventions at the CMOP-E level of 'person' could therefore also include participation in activities that develop both motor and Executive Function skills simultaneously such as yoga or dynamic sports (e.g. wresting). This is supported by evidence of improved Executive Function performance in typically developing groups following daily yoga practice (Manjunath &Telles 2001) and engagement in complex sports similar to freestyle wrestling (Moreau et al., 2015). However, further research is needed to examine the effect of this type of intervention on children with DCD, including any potential real-world impact, and persistence of any improvements seen.

As Study One found that many children with DCD experience Executive Function difficulties this could suggest that interventions which teach specific motor skills in a way which limits the need for Executive Function skills from the child, such as Neuromotor Task Training (Schoemaker et al., 2003) would be best for children with DCD. However, whilst this technique has been found to improve overall motor performance (Preston et al., 2017) and is recommended in the International

Guidelines for DCD, so are interventions which actively recruit Executive Function in problem solving, such as CO-OP. The CO-OP approach, as mentioned above (section 11.5.1.) and previously discussed in chapter two (section 2.8.1.) uses the Executive Function skills of the child to achieve activity performance. CO-OP has been found to be successful in enabling children with DCD to achieve the three functional goals outlined in therapy (Novak & Honan, 2019) as well as to improve overall motor performance (Anderson et al., 2018). Capistran and Martini (2016) have also found preliminary evidence of successful transfer to non-trained goals in children with DCD. This suggests that CO-OP may improve children's problem-solving ability and therefore their Executive Function skills. There is also evidence that children with ADHD improve on parent/carer reported Executive Function skills following intervention (Gilboa & Helmer, 2019). Therefore, it appears that CO-OP may have wider benefits to children with DCD beyond the achievement of therapy goals and improved general motor skills. Considering the results of Study One and the potential for broader benefits following CO-OP intervention, for both motor and Executive Function skills, CO-OP may be preferable to interventions that explicitly teach tasks through limiting the Executive Function involvement for children with DCD. However, the potential influence of CO-OP on Executive Function skills more broadly has not yet been examined in a group of children with DCD and this is recommended as an area for future research.

11.6. Directions for Future Research

Several limitations of Study One and Two were considered in section 11.3. and some suggestions for future research were provided such as the consideration of Inhibition skills in other developmental conditions (e.g. ASC, ADHD), and the effect of response modality in these populations using tasks such as the AdVIMI. This section considers some additional suggestions for how future work could build on the findings of Study One and Two.

Study One and Two considered Executive Function and Inhibition specifically in everyday life using parent/carer and teacher questionnaires. The BRIEF-2 has a self-assessment form for children aged 11-18 years so could not be used with the six to ten year old participants of Study One and Two. It is important for future research to consider the perspectives of children themselves. Varni et al. (2007) have found that children as young as five years are able to provide a reliable self-report of their ability. Importantly, previous research has also found that a parent/carer report is not equivalent to child self-report and should not be used as a substitute (Theunissen et al., 1998). Future research should develop questionnaires or reporting mechanisms for children aged five to ten which can provide their perspectives on their Executive Function skills in everyday life.

As well as behavioural measures this research should include task based functional magnetic resonance imaging (fMRI) with children with and without DCD to understand the neural correlates that underlie brain function in these groups. This research should use a range of verbal and motor tasks assessing Response Inhibition and Interference Control to account for issues such as task impurity. It should also have a large sample with a narrow age range to reduce the impact of developmental differences. It would also be beneficial to measure the frequency of engagement in sporting activities and sedentary time of the children in both groups and consider the impact of this on the results. fMRI could be used to investigate a range of Inhibition and motor tasks, in mixed samples of children with DCD, ASC, ADHD and dual diagnoses. The use of brain imaging could provide an insight into the neural networks involved in these tasks and examine if and/or how they may differ across these conditions. This research would not only build on the findings of Inhibition difficulties in children with DCD from Study One by suggesting potential underlying mechanisms for the Inhibition difficulties observed but it would also further the understanding of why relationships between Inhibition and motor skills were observed in Study Two.

A further important area of research is the impact of improved awareness of Executive Function and Inhibition specific difficulties in DCD on the self-esteem and mental health of children with the condition. Further research could investigate whether parental, teacher and child education on the Executive Function challenges associated with DCD has any impact on reducing the rate of potential secondary consequences of DCD such as low self-esteem and internalising symptoms, discussed in Chapter two section 2.6.4.

11.7. Conclusions

- The poorer performance of children in the DCD group on measures of Response Inhibition and Interference Control when a motor and verbal response was required, suggest that the skill automatisation deficits hypothesis and limited attention capacity cannot singularly account for the motor difficulties central to DCD.

- The poorer Executive Function skills in the DCD group and relationships between Motor and Executive Function skills found, support theories that Executive Function difficulties may be an underlying mechanism for DCD, and that those with DCD may have shared biological mechanisms which contribute to their difficulties. Behavioural explanations such as decreased participation in sports for children with DCD could also explain the group differences and relationships found.
- The variability in Executive Function and Inhibition specific performance of the DCD group suggests that Executive Function difficulties should not be considered a core defining symptom for children with DCD at a single point in time. Executive Function should instead be routinely included in DCD assessments and frequently reviewed, guided by a model such as CMOP-E which can account for this inherent complexity and individual variability.
- The poorer performance of children in the DCD group on Executive Function performance measures and questionnaires means that they should have access to interventions that lessen the impact of their difficulties. Intervention should be aligned to a model such as the CMOP-E which can support a focus on increased participation in everyday contexts.

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Appendix A: Intelligence and Developmental Scales 2nd Edition Tasks from Full Battery

No	Task	Age	Description
Intelligence			
1	Shape Design	5-20	Reproducing geometric shapes using rectangles and triangles
2	Story Recall	*5-20*	*Listening to a semantically meaningful story and recalling it with cues after at least 20 minutes*
3	Processing Speed Parrots	*5-20*	*Crossing out parrots with two orange features that look to the left, as quickly as possible in rows of different parrots*
4	Digit and Letter Span	*5-20*	*Repeating number and letter sequences forwards and backwards*
5	Shape Memory	*5-20*	*Remembering figures and recognising their shapes and positions from a selection*
6	Matrices: Completion	*5-20*	*Identifying how a figure changes and applying this change to another figure*
7	Naming Categories	*5-20*	*Naming the correct category for a group of pictures or concepts*
8	Washer Design	*5-20*	*Placing washers according to a template pattern*
9	Picture Recall	*5-20*	*Looking at a picture and describing it freely and with cues after at least 20 minutes*
10	Processing Speed Boxes	*5-20*	*Crossing out groups of 3 or 4 boxes as quickly as possible in rows of different groups of boxes*
11	Mixed Digit and Letter Span	*5-20*	*Repeating mixed sequences of numbers and letters forwards and backwards*
12	Rotated Shape Memory	*5-20*	*Remembering figures and recognising their shapes and positions from a selection of rotated figures*
13	Matrices: Odd One Out	*5-20*	*Looking at a number of pictures and deciding which one doesn't fit*
14	Naming Opposites	*5-20*	*Stating the opposites of given words*
Executive Function			
15	Listing Words	*5-20*	Listing as many words as possible from a category within a time limit
16	Divided Attention	*5-20*	Listing as many animals as possible from a category whilst also crossing out parrots from a sheet of distractors
17	Animal Colours	*5-20*	List the correct colour of the animal despite the presenting colour
18	Drawing Routes	*5-20*	Quickly and accurately complete mazes without drawing over the same path more than once
Psychomotor Skills			
19	Gross Motor skills	*5-10*	Balancing on a rope; Throwing and catching; jumping over a rope;
20	Fine Motor Skill	*5-20*	Threading beads and screwing and unscrewing nuts onto bolts
21	Visuomotor Skill	*5-20*	Drawing in between lines; copying images; completing mirror images
Social-Emotional Skills			
22	Identifying Emotions	*5-10*	Correctly identifying the emotions of children in pictures
23	Regulating Emotions	*5-20*	Explaining how they would regulate their emotions in different situations
24	Socially Competent Behaviour	*5-20*	Explaining how they would react in a range of situations
Basic Skills			
25	Logical Mathematical Reasoning	*5-20*	Completing increasing complex mathematical challenges
26	Language Skills	*5-10*	Language tasks such as syllable recognition
27	Reading	*7-20*	Reading passages and answering questions
28	Spelling	*7-20*	Spelling increasing complex words

Appendix B: Analysis of Results Controlling for Hyperactivity

Table B.1.

Results of ANCOVA controlling for the effect of hyperactivity as a covariate on BRIEF-2 Parent/Carer Questionnaire

Measure	Main Effect of Group (n =50)	Main Effect of Covariate (Hyperactivity)
Inhibit	$F(1, 47) = .63$, $p = .43$, n^2p .01	$F(1, 47) = 14.46$, $p < .001$, n^2p.24
Self Monitor	$F(1, 47) = .85$, $p = .36$, n^2p .018	$F(1, 47) = 5.36$, $p = .03$, n^2p .10
Emotional Control	$F(1, 47) = .91$, $p = .35$, n^2p .02	$F(1, 47) = .82$, $p = .37$, n^2p .02
Emotional Regulation Index (ERI)	$F(1, 47) = 1.69$, $p = .20$, n^2p .04	$F(1, 47) = 2.38$, $p = .13$, n^2p .05
Initiate	$F(1, 47) = 7.91$, $p < .01$, n^2p.14	$F(1, 47) = 5.27$, $p = .03$, n^2p.10
Working Memory	$F(1, 47) = 5.53$, $p = .02$, n^2p.105	$F(1, 47) = 12.51$, $p < .001$, n^2p .21
Plan	$F(1, 47) = 7.62$, $p < .01$, n^2p .14	$F(1, 47) = 12.65$, $p < .001$, n^2p.21
Task Monitor	$F(1, 47) = 29.43$, $p < .001$, n^2p .39	$F(1, 47) = 5.7$, $p = .02$, n^2p .11
Organisation of materials	$F(1, 47) = 13.78$, $p < .001$, n^2p .23	$F(1, 47) = .244$, $p = .62$, n^2p .01
Cognitive regulation Index (CRI)	$F(1, 47) = 20.12$, $p < .001$, n^2p .30	$F(1, 47) = 8.10$, $p < .01$, n^2p .15
Global Executive Composite (GEC)	$F(1, 47) = 10.2$, $p < .01$, n^2p .18	$F(1, 47) = 10.7$, $p < .01$, n^2p .19

Table B.2.

Results of ANCOVA Controlling for the Effect of Hyperactivity on BRIEF-2 Teacher Questionnaire

Measure	Main Effect of Group (n = 29)	Main Effect of Covariate (Hyperactivity)
Self Monitor	F(1, 26) = 0.02, p <.890, n^2p 0.00	F(1, 26) = 3.53, p <.0720, n^2p 0.12
Behaviour Regulation Index (BRI)	F(1, 26) = 0.01, p <.940, n^2p 0.00	F(1, 26) = 3.97, p <.057, n^2p 0.13
Shift	F(1, 26) = 0.74, p <.398, n^2p 0.03	F(1, 26) = 2.47, p <.128, n^2p 0.09
Plan	F(1, 26) = 0.69, p <.415, n^2p 0.03	F(1, 26) = 6.31, p <.019, n^2p 0.20
Task Monitor	F(1, 26) = 9.88, p <.004, n^2p 0.28	F(1, 26) = 0.19, p <.668, n^2p 0.01
Global Executive Composite (GEC)	F(1, 26) = 2.33, p <.139, n^2p 0.08	F(1, 26) = 5.61, p <.026, n^2p 0.18

Table B.3.

Results of ANCOVA Controlling for the Effect of Hyperactivity on IDS-2-EF

Measure	Main Effect of Group (n =50)	Main Effect of Covariate (Hyperactivity)
Listing Words	F(1, 47) = 1.14, p =.291, n^2p .02	F(1, 47) = 0.01, p =.901, n^2p .00
Divided Attention – Animal Listed	F(1, 47) = 1.75, p =.193, n^2p .04	F(1, 47) = 1.18, p =.282, n^2p .02
Divided Attention – Parrots Crossed out	F(1, 47) = .16, p =.694, n^2p .00	F(1, 47) = 1.79, p =.188, n^2p .04
Drawing Routes Time	F(1, 47) = .13, p =.724, n^2p .00	F(1, 47) = 0.04, p =.849, n^2p .00
Drawing Routes Quality	F(1, 47) = 1.45, p =.234, n^2p .03	F(1, 47) = 0.00, p =.945, n^2p .00

Table B.4.

Results of ANCOVA Controlling for the Effect of Hyperactivity on AdVIMI Motor Task

Measure	Main Effect of Group (n =50)	Main Effect of Covariate (Hyperactivity)
AdVIMI Incongurent Error rate	$F(1, 47) = 2.18$, $p = .147$, n^2p .04	$F(1, 47) = .80$, $p = .375$, n^2p .02
AdVIMI Motor Incongruent RT	$F(1, 47) = .13$, $p = .720$, n^2p .00	$F(1, 47) = 0.06$, $p = .811$, n^2p .00
AdVIMI Motor Incongruent Movement Time	$F(1, 47) = 19.61$, $p = <.001$, n^2p .29	$F(1, 47) = 7.77$, $p = .008$, n^2p .14

Appendix C: AdVIMI Instructions

AdVIMI Verbal congruent condition

Tester: In this task you will see some pictures on the screen, sometimes you will say what the picture is and sometimes I will ask you to say something different, I'd like you to say the word as quickly as possible but we'll have a practice first

I would like you to wear this headset so that I can hear you better, you won't hear any noise through it

When you see this picture (doll) you say doll
When you see this picture (car) you say car
Now you try, when you see this picture (doll) you say *(Tester waits for child's response)*
Child: 'doll'
Tester: 'That's right''
'And when you see this picture (car) you say (*Tester waits for child's response*)
Child: 'car'
Tester: 'That's right. Let's practice'
Testers responses to practice: 'That's right' *or* 'remember when you this this picture you say (*Tester provides the correct response)*
When practice is over Tester says: 'Well done, do you have any questions? let's go.' *or* 'let's recap'

20 trials

AdVIMI Verbal Incongruent Condition

Tester: Now we are going to do something different
Now, when you see this picture (doll) you say car
And when you see this picture (car) you say doll
Now you try, When you see this picture (doll) you say car
And when you see this picture (car) you say doll
Let's practice, remember to respond as quickly as possible
Testers Reponses to practice: 'That's right' *or* 'remember when you see this picture you do this and demonstrate'
When practice is over Tester says: 'Well done, do you have any questions? let's go.' *or* 'let's recap'

20 trials

AdVIMI Motor Congruent Condition

Tester: In this task you will see some pictures on the screen of me doing different things, sometimes I'll ask you to copy what I am doing and sometimes I'll ask you to do something different, I'd like you to move as quickly as possible but we'll have a practice first. You must always start with your hands on this mat and you must make sure you put your hands back on the mat after every go.

When you see a picture of me do this (point finger picture) you do this *point finger video*
When you see a picture of me do this (Fist picture) you do this *fist video*
Make sure to always put your hands back on the mat and move as quickly as possible, you'll see this picture to remind you.
Now you try, when you see a picture of me do this (point finger picture) you do this *point finger video*
When you see a picture of me do this (Fist picture) you do this *fist video*
'Let's practice
Testers responses to practice: 'That's right' *or* 'remember when you see this image you do this and demonstrate'

When practice is over Tester says: 'Well done, Do you have any questions? Put your hand on the mat and let's go.' *or* 'let's recap'

20 trials

AdVIMI Motor Incongruent Condition

Tester**:** 'Now we are going to do something different'
When you see a picture of me do this (point finger picture) you do this *fist video*
'When you see a picture of me do this (Fist picture) you do this *pointed finger video*
Now you try, when you see a picture of me do this (point finger picture) you do this *fist video*
And, when you see a picture of me do this (Fist picture) you do this *pointed finger video*
Remember to put your hands back on the mat after every go and move as quickly as possible
Let's practice
Testers responses to practice: 'that's right' or 'remember when you see this image you do this and demonstrate'
When practice is over Tester says: 'Well done, do you have any questions? Put your hand on the mat and let's go.' *Or* 'let's recap'

20 trials

Appendix D: AdVIMI Scoring

Verbal

Time

- RT – Starts from stimulus display. Ends at first sound of the first attempted response

Error

- Correct = 0
- Corrected = 1 *(if correct answer is given within 90 milliseconds(ms) of image being displayed*
- Incorrect = 2

Motor

Time

- RT – Starts from stimulus display Ends at first purposeful movement of hands towards action
- MT – Starts from stimulus display sends when hand is still in place in final posture

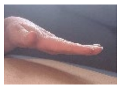
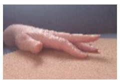
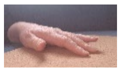
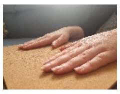
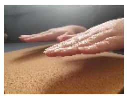
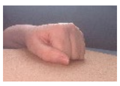
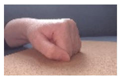
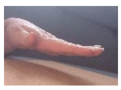
Error

- Correct = 0
- Corrected* = 1 (for pointed finger, thumb up doesn't count as a corrected as some children always leave their thumb up)
- Incorrect = 2

*An item is scored as corrected if a move toward correction occurs a maximum of 50ms from the hand being still in the incorrect position.

Table D.1.

Hand movement from Mat Codes

Hand Movement Description	Hand Start Position	Hand Movement	Code
Whole hand moves vertically off the mat in one movement			A
Whole hand moves vertically off the mat but fingers do not move in unison (i.e. fingers move one at a time)			B
Whole hand slides horizontally on the mat toward the child's body before being raised.			C
Hands are not kept still when waiting (fidgeting), first purposeful movement to make the response action is counted.			D
Hand flat on mat, palm arches and fingers follow.			E
Hand leaves the mat; hand is then placed back down onto the mat before being lifted off the mat again.		  	F
Two hands are lifted off the matt to respond			G
Unable to categorise movement (This includes if the hand moves from a fist position on the mat)			H
Hand responds from mid air			I

Appendix E: Details of Flanker Task Adaptations from Studies Using Children

	McDermott et. al (2007)	ANT. Rueda et al., (2004)	Bervoets et al., (2018)	Johnstone, Galletta (2013)	Konijnenberg & Fredriksen (2018)	National Institute of Health (NIH) Toolbox Gershon, et al., (2009)
Ages	3-6 years	6-9 years	9-11 years	7-14 years	7-8 years	3-15 years
Stimuli	Colours, shapes & fish	Fish	Letters	< >	Fish	Fish & arrow
Neutral presentation included	No	Yes (Solo fish)	No	Yes (==>==)	No	No
Congruent/Incongruent Ratio	50/50	50/50	50/50	50/50	50/50	56.25% C (16/9)
Inter-trial interval:	3,900-4,400 ms (random variation)	400 – 1600 ms (random variation)	-	250ms-6250ms	1500ms	800ms
Warning (+)	300 ms	150 ms changed mind	-	-	-	1000-1500ms
Fixation (MIDDLE)	500 ms	450 ms	500ms	500ms	-	1000ms
Flanker priming effect		No, appeared at same time	200ms		-	100ms
Time given to respond	1,300 ms	1,700 ms changed mind	1400ms	1500ms	3000ms	10000ms
Practice trials	8	24	18	16	40	4*
Experimental Blocks	3	3	3	3	3	2 1 fish and if 5/9 incongruent correct 1 arrow
Trials per block	32	48 changed mind too long	48	120	40	25
Feedback during trial	Happy, sad face 800ms	Yes, fish blow bubbles and 'woo, hoo' sound or single tone and no animation	No (only in practice, verbal correct or not)	-	-	no

Appendix F: AdFlanker Rational for Design

		Adapted "Fish Flanker" task used in current study	Aligned with:	Reasoning
Ages		6-10 years		Ceiling effects noted in children older than 10 years (Bervoets et al., 2018)
Stimuli		Fish	Rueda *et al.* 2004	Consistent presentation, appealing to younger children
Neutral presentation included		No	Gershon, *et al.,* 2009	Trial not required and would make task longer introducing additional attentional demands.
C/I Ratio		27c/21ic (56.25%)	Gershon, *et al.,* 2009	To elicit the largest opportunity for interference within the smallest time, this ratio was chosen. Gratton, Coles, & Donchin, (1992) found RTs on incongruent trials were faster following incongruent trials, than following congruent trials.
Inter-trial interval:		800ms	Gershon, *et al.,* 2009	Chosen over the random variation used in other adaptations of the flanker task (McDermott et al., 2007; Rueda et al., 2004) to reduce introducing a potential confounding variable.
Fixation	+	1000ms	Gershon, *et al.,* 2009	Different times were piloted from other flanker variations this was the most appropriate.
Cue	None		Konijnenberg & Fredriksen 2018	Audio cue 'middle' in line with Gershon et al., (2013) was piloted and participants found it distracting so it was removed.
Flanker priming effect	(flanking stimuli appear 1st)	100ms	Gershon, *et al.,* 2009	Priming enables processing in greater detail (Flowers, 1990)
Respond within …		10,000ms	Gershon, *et al.,* 2009	Longer time used to enable all RTs to be compared between groups. Important to not exclude children because they couldn't press the screen in time.
Practice trials		4*	Gershon, *et al.,* 2009	Four with the exclusion criteria was adequate in pilot, reduces length of task, and minimises any potential practice effects.
Experimental Blocks		2	Gershon, *et al.,* 2009	Most other flanker adaptations use three blocks, however, two reduces the length of testing and minimises fatigue and attentional demands.
Trials per block		25	Gershon, *et al.,* 2009	This was adequate to keep children engaged and gain sufficient data.
Feedback during trial		No	Gershon, *et al.,* 2009	Could act as a distractor, there might be greater individual differences in how children respond to feedback.
Presentation order		Same for all participants		Minimises individual differences and allows for group comparison

Appendix G: AdFlanker Instructions Script

Tester: In this task you will see a row of fish pointing different ways, but first we are going to learn about the Start Spot. Put your finger on the Start Spot and wait for the picture.
Here is a fish! Here is its head, here is its tail. The fish is pointing this way, the same way it is swimming.
Can you point to the middle fish?
Look at all the fish. The fish in the middle is hungry.
To feed the middle fish choose an arrow down here which matches the way the middle fish is pointing.
Here the middle fish is pointing this way so I will choose this button

Here the middle fish is pointing this way, so I will choose this button

Sometimes all the fish point the same way. Sometimes the MIDDLE fish points a different way, like this: you should choose the button that matches the way the MIDDLE fish is pointing.
Here the middle fish is pointing this way so I will choose this button

Here the middle fish is pointing this way so I will choose this button

Now you try, keep your eyes on the cross in the middle of the screen and press the arrows as quickly as you can. Put your finger back on the start spot after each turn.

Practice one response: ‘Well Done’ *or* ‘the MIDDLE fish is pointing this way so you should choose this button’ *correct button lights up*
After Practice: ‘Do you have any questions? Now remember to put your finger back on the start spot after every go and press the arrow as quickly as you can’.

Additional Notes
The first child tested looked away from the screen and missed the first fish. The instructions were then amended so the tester said ‘ready, steady, go’ before starting the formal trials for every other child.

Appendix H: UREC Approval Letter

OXFORD BROOKES UNIVERSITY

Professor Anna Barnett
Director of Studies
Department of Psychology, Health and Professional Development
Faculty of Health and Life Sciences
Oxford Brookes University
Headington Campus

4 May 2018

Dear Professor Barnett

UREC Registration No: 181186
An examination of motor and executive function skills in children with and without Developmental Coordination Disorder

Thank you for the email of 26 April 2018 outlining the response to the points raised in my previous letter about the PhD study of your research student Teresa Joyce and attaching the revised documents. I am pleased to inform you that, on this basis, I have given Chair's Approval for the study to begin.

The UREC approval period for the data collection phase of the study is two years from the date of this letter, so 4 May 2020. If you need the approval to be extended please do contact me nearer the time of expiry.

Should the recruitment, methodology or data storage change from your original plans, or should any study participants experience adverse physical, psychological, social, legal or economic effects from the research, please inform me with full details as soon as possible.

Yours sincerely

Dr Sarah Quinton
Chair of the University Research Ethics Committee

cc Nichola Stuart and Serena Vanzan, Supervisory Team
Teresa Joyce, Research Student
Morag MacLean, Research Ethics Officer
Jill Organ, Research Degrees Team
Louise Wood, UREC Administrator

www.brookes.ac.uk

Appendix I: Participant Information Sheet for Children with DCD

FACULTY OF HEALTH AND LIFE SCIENCES
Headington Campus
Gipsy Lane
Oxford OX3 0BP

Principal Investigator: Teresa Joyce
E-mail: teresa.joyce-2017@brookes.ac.uk
Telephone: 01865 483776
Director of Studies: Prof Anna Barnett
Email: abarnett@brookes.ac.uk
Tel: 01865 483 680

Dear Parent/Guardian,

Project: '**An Examination of Motor and Executive Function skills in Children'**
Funded by Hogrefe Ltd.

Your child has been invited to take part in the above research project. Before you decide whether to allow them to take part, please read the following information.

What is the purpose of the project? This project is being carried out alongside the standardisation of the IDS-2 (Intelligence & Development Scales 2nd edition), which you have already agreed to take part in. A standardised test allows for the performance of an individual to be compared to a representative sample of the population, allowing for their strengths and difficulties to be identified. The IDS-2 is designed to be used by educational and health professionals to help them assess performance across a range of tasks to identify those with difficulties and to provide appropriate support for people to reach their potential.

The current project focuses in more detail on two parts of the IDS-2 to check that they are working properly. The focus is on the Motor tasks (assessing balance, agility, catching/ throwing and hand skills) and the tasks assessing mental flexibility when naming colours and listing words. To check that these give accurate results we need to compare them against other similar motor and Executive Function tests in a range of children.

What will my child be asked to do? If you decide to allow your child to take part, they will be asked to perform a further set of Executive Function tasks. The Executive Function tasks include inhibiting a response (e.g. doing an opposite action to what the tester is doing for example 'touch your toes when the tester touches their head'). We ask for your permission to audio/video your child to help score their performance. These recordings will be used to accurate score the assessment and will then be deleted. Your child will be asked to complete these tasks across one sessions with me lasting no more than 30 minutes. I am a qualified Occupational Therapist with experience working with children in this age group. As parent/guardian we also ask that you complete a questionnaires about your child, which will take approximately 5-10 minutes each and your child's teacher will be asked to complete a short questionnaire. These will ask about your child's motor skills in everyday activities, attention and behaviour.

Where will the research take place? You and your child will be invited to Oxford Brookes University or a location which is convenient for you (such as your home or your child's school). The sessions will run on different days, organised for a time suitable for your child and the teacher. Parents/Guardians will not be in the same room as the children during testing, but they will be close by.

Why has my child been invited to participate? We are inviting children aged 5.0-9.11 years who have already agreed to take part in the broader IDS-2 project to take part in this study. We are looking to recruit a minimum of 48 children. We are not able to include children with a severe sensory, intellectual or physical disability, as they would find it difficult to understand or attempt the tasks.

Does my child have to take part? Your child is under no obligation to take part in this research. Before the sessions begin your child will also be asked if they are happy to take part. Even if you do give consent, you and/or your child are free to withdraw from this research at any time and without giving a reason. Although you and/or your child may withdraw at any time, only unprocessed data may be withdrawn from the study.

What are the possible benefits of taking part? This research will help us to check that the IDS-2 is accurate for young children. By taking part in this project your child will be helping to ensure that other children receive the support they need in the future. Most children enjoy completing the tasks, many of which are like games. If your child is seen at school your child will not be taken out of classes they are required to attend or which they would be particularly upset at missing.

Will what I say in this study be kept confidential? All the information collected about your child will be kept strictly confidential (subject to legal limitations). Any information that could identify them will be removed from the data and replaced by a code. Data generated by the study will be kept by Hogrefe Ltd. and Oxford Brookes University. It must be retained in accordance with the University's policy on Academic Integrity and may be used for future research; thus, must be kept securely in paper or electronic form for a period of ten years after the completion of the research project.

What should I do if I want to take part? If you wish to give permission for your child to take part please contact me, Teresa Joyce using either the phone number or email address above.

What will happen to the results of the research study? Some of the overall findings from this research will be included in the technical manual of the IDS-2, which will be published by Hogrefe Ltd. Findings from the research may also be published in scientific journals. They will also be disseminated to other colleagues and the public at conferences and seminars. Individuals will not be identified in any publication. A summary of some aspects of the research will be available on the webpage of the research programme: https://www.brookes.ac.uk/phpd/psychology/research/groups/developmental-psychology/development-of-ids-2/

Who has reviewed the study? The research has been approved by the University Research Ethics Committee, Oxford Brookes University (Ethics number: 181186)

Contact for Further Information
If you have any questions, you can contact me, using the contact details at the top of this information sheet. If you have any concerns about the way the study has been conducted, you should contact the Chair of the University Research Ethics Committee on ethics@brookes.ac.uk.

Thank you very much for taking the time to read this information sheet.

Teresa Joyce

Date

21.05.2018

Appendix J: Participant Information Sheet for TD Children

FACULTY OF HEALTH AND LIFE SCIENCES
Headington Campus
Gipsy Lane
Oxford OX3 0BP

Principal Investigator: Teresa Joyce
E-mail: teresa.joyce-2017@brookes.ac.uk
Telephone: 01865 483776
Director of Studies: Prof Anna Barnett
Email: abarnett@brookes.ac.uk
Tel: 01865 483 680

Dear Parent/Guardian,

Project: '**An Examination of Motor and Executive Function skills in Children'**
Funded by Hogrefe Ltd.

Your child has been invited to take part in the above research project. Before you decide whether to allow them to take part, please read the following information.

What is the purpose of the project? This project is being carried out alongside the standardisation of the IDS-2 (Intelligence & Development Scales 2nd edition), which you have already agreed to take part in. A standardised test allows for the performance of an individual to be compared to a representative sample of the population, allowing for their strengths and difficulties to be identified. The IDS-2 is designed to be used by educational and health professionals to help them assess performance across a range of tasks to identify those with difficulties and to provide appropriate support for people to reach their potential.

The current project focuses in more detail on two parts of the IDS-2 to check that they are working properly. The focus is on the Motor tasks (assessing balance, agility, catching/ throwing and hand skills) and the tasks assessing mental flexibility when naming colours and listing words. To check that these give accurate results we need to compare them against other similar motor and Executive Function tests in a range of children.

What will my child be asked to do? If you decide to allow your child to take part, they will be asked to perform a further set of motor and Executive Function tasks. The motor tasks include balance, jumping, throwing and catching. The Executive Function tasks include inhibiting a response (e.g. doing an opposite action to what the tester is doing for example 'touch your toes when the tester touches their head'). We ask for your permission to audio/video your child to help score their performance. These recordings will be used to accurate score the assessment and will then be deleted. Your child will be asked to complete these tasks across one sessions with me lasting no more than 90 minutes each, including a break. I am a qualified Occupational Therapist with experience working with children in this age group. As parent/guardian we also ask that you complete two questionnaires about your child, which will take approximately 5-10 minutes each and your child's teacher will be asked to complete a short questionnaire. These will ask about your child's motor skills in everyday activities, attention and behaviour.

Where will the research take place? You and your child will be invited to Oxford Brookes University or a location which is convenient for you (such as your home or your child's school). The sessions will run on different days, organised for a time suitable for your child and the teacher. Parents/Guardians will not be in the same room as the children during testing, but they will be close by.

Why has my child been invited to participate? We are inviting children aged 6.0-10.11 years who have already agreed to take part in the broader IDS-2 project to take part in this study. We are looking to recruit a minimum of 48 children. We are not able to include children with a severe sensory, intellectual or physical disability, as they would find it difficult to understand or attempt the tasks.

Does my child have to take part? Your child is under no obligation to take part in this research. Before the sessions begin your child will also be asked if they are happy to take part. Even if you do give consent, you and/or your child are free to withdraw from this research at any time and without giving a reason. Although you and/or your child may withdraw at any time, only unprocessed data may be withdrawn from the study.

What are the possible benefits of taking part? This research will help us to check that the IDS-2 is accurate for young children. By taking part in this project your child will be helping to ensure that other children receive the support they need in the future. Most children enjoy completing the tasks, many of which are like games. If your child is seen at school your child will not be taken out of classes they are required to attend or which they would be particularly upset at missing.

Will what I say in this study be kept confidential? All the information collected about your child will be kept strictly confidential (subject to legal limitations). Any information that could identify them will be removed from the data and replaced by a code.. Data generated by the study will be kept by Hogrefe Ltd. and Oxford Brookes University. It must be retained in accordance with the University's policy on Academic Integrity and may be used for future research; thus, must be kept securely in paper or electronic form for a period of ten years after the completion of the research project.

What should I do if I want to take part? If you wish to give permission for your child to take part please contact me, Teresa Joyce using either the phone number or email address above.

What will happen to the results of the research study? Some of the overall findings from this research will be included in the technical manual of the IDS-2, which will be published by Hogrefe Ltd. Findings from the research may also be published in scientific journals. They will also be disseminated to other colleagues and the public at conferences and seminars. Individuals will not be identified in any publication. A summary of some aspects of the research will be available on the webpage of the research programme: https://www.brookes.ac.uk/phpd/psychology/research/groups/developmental-psychology/development-of-ids-2/

Who has reviewed the study? The research has been approved by the University Research Ethics Committee, Oxford Brookes University (Ethics number: 181186)

Contact for Further Information
If you have any questions, you can contact me, using the contact details at the top of this information sheet. If you have any concerns about the way the study has been conducted, you should contact the Chair of the University Research Ethics Committee on ethics@brookes.ac.uk.

Thank you very much for taking the time to read this information sheet.

Teresa Joyce

Date

03.10.2018

Appendix K: Consent Form for Children with DCD and TD Controls

CONSENT FORM

Project: '**An Examination of Motor and Executive Function skills in Children**'

Principle Investigator: Teresa Joyce; Tel: 01865 4833776; Email: teresa.joyce-2017@brookes.ac.uk

Prof Anna Barnett: Tel: 01865 483680; Email: abarnett@brookes.ac.uk

Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX3 0BP

Please **initial** box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐
2. I understand that my child's participation is voluntary and he/she is free to withdraw at any time, without giving reason. ☐
3. I agree for my child to take part in the above study. ☐
4. I agree that any identifying information will be removed from the data and that data will be accessible only to the responsible researchers, subject to legal limitations. ☐
5. I agree for my child to be audio recorded ☐
6. I agree for my child to be video recorded ☐

Please **initial** box

	Yes	No
7. I agree to be contacted by the research team again in the future to consider taking part in further research.	☐	☐

________________________ ________________ ______________

Name of **Child** (please print) Date of Birth Age

________________________ ________________ ______________

Name of **Parent/Carer** (please print) Date Signature

Appendix L: Analysis of Results with children with DCD without Co-occurring Conditions and TD Matched Controls

Table L.1.

Results of Group Comparisons of BRIEF-2 Parent/Carer Questionnaire for Children with DCD and TD Matched Controls Excluding Children with Co-occurring Conditions

Measure	DCD (n = 18) Mean (SD) Range	TD (n = 18) Mean (SD) Range	t (34)/U	p	Cohen's d	95% Confidence Intervals
Inhibit	*56.7 (9.22) (41-75)*	*49.1 (10.1) (38-69)*	t 2.36	.024	.79	1.05 -14.17
Self Monitor	*55.60 (12.40) (39-78)*	*48.8 (10.3) (45-72)*	u 104	.066	.67	-.10 – 14.87
Behavioural Regulation Index (BRI)	*56.6 (9.69) (45-72)*	*48.8 (10.3) (37-68)*	u 85.50	.016	.77	2.00 -15.00
Shift	*58.10 (11.9) (39-79)*	*50.70 (10.80) (39-76)*	t 1.96	.058	.65	-.026 – 15.15
Emotional Control	*57.60 (11.9) (40-79)*	*53.00 (12.20) (40-82)*	t 1.15	.260	.38	-3.57 – 12.79
Emotional Regulation Index (ERI)	*58.3 (11.60) (39-79)*	*52.2 (9.69) (39-66)*	t 1.72	.095	.57	-1.12 – 13.34
Initiate	*60.3 (8.76) (40-75)*	*46.7 (9.55) (38-67)*	t 4.44	≤ .001	1.48	7.35 – 19.76
Working Memory	*62.9 (9.42) (41-77)*	*48.0 (9.81) (38-69)*	t 4.64	≤ .001	1.55	8.37 – 21.40
Plan	*62.30 (8.46) (45-66)*	*49.8 (8.73) (37-66)*	t 4.36	≤ .001	1.45	6.68 – 18.32
Task Monitor	*65.40 (6.44) (50-73)*	*46.3 (8.04) (35-66)*	t 7.88	≤ .001	2.63	14.18 – 24.04
Organisation of materials	*64.40 (8.86) (42-76)*	*50.0 (8.84) (38-67)*	t 4.75	≤ .001	1.58	8.01 – 19.99
Cognitive regulation Index (CRI)	*64.40 (6.30) (47-75)*	*48.1 (8.85) (39-66)*	U 24	≤.001	2.12	11.07 – 21.48
Global Executive Composite (GEC)	*64.9 (8.32) (44-77)*	*50.10 (10.00) (39-71)*	t 4.82	≤ .001	1.61	8.55 -21.01

The results displayed in Table L1 appear to align more closely to the responses on the Teacher Questionnaire from the full sample (n = 29) rather than the Parent/Carer Questionnaire for the full sample (n =50). This may suggest that results from the Parent/Carer and Teacher Questionnaire differ because the sample of children with a Teacher questionnaire included less children with co-occurring conditions. However, the full sample of children with a Teacher questionnaire included all but one of the children with cooccurring conditions (six with DCD and co-occurring condition). Therefore, this could not explain the differences between the Parent/Carer and Teacher questionnaires.

Table L.2.

A Comparison of Mean (SD) IDS-2-EF Scores for Children with DCD and TD Matched Controls Excluding Children with Co-occurring Conditions

Measure	DCD (n = 18) Mean (SD)	TD (n = 18) Mean (SD)	t(34)/U	p	Cohen's d	95% Confidence Interval
Listing Words No. words listed	43.44 (15.79)	47.78 (11.69)	t 1.15	.257	-.38	-14.74 – 4.08
Divided Attention – Animals Listed	14.78 (6.05)	20.39 (6.08)	t 2.77	.009	-.92	-9.72 - -1.50
Divided Attention – Parrots crossed out	19.94 (8.34)	22.06 (10.45)	t -.67	.508	-.22	-8.52 – 4.29
Animal Colours Time Raw	58.82 (23.67)	41.33 (13.80)	U 80.50	.010	.90	3.06 – 27.05
Drawing Routes Time	22.11 (9.04)	22.44 (8.36)	t -.11	.909	-.04	-6.23 – 5.56
Drawing Routes Quality	16.78 (5.65)	20.61 (6.10)	t -1.96	.059	-.07	-7.82 – 0.15

Table L.3.

A Comparison of Mean (SD) AdFlanker Scores for Children with DCD and TD Matched Controls Excluding Children with Co-occurring Conditions

Measure	*DCD (n = 18) Mean (SD)*	*TD (n = 18) Mean (SD)*	*U*	*p*	*Cohen's d*	*95% Confidence Intervals*
AdFlanker Congruent Error rate	.72 (1.96)	.11 (.32)	151.00	.580	.43	-.34 – 1.56
AdFlanker Congruent RT	2.44 (.45)	2.18 (.13)	122.00	.214	.77	-.06 - .48
AdFlanker Incongruent Error rate	.44 (.98)	.17 (.51)	136.00	.242	.35	-.025 – 0.81
AdFlanker RT Incongruent	2.45 (.39)	2.24 (.16)	121	.203	.69	-.07 – .41

Table L.4.

A Comparison of Mean (SD) AdAC Scores for Children with DCD and TD Matched Controls Excluding Children with Co-occurring Conditions

Measure	DCD (n = 18) Mean (SD)	TD (n = 18) Mean (SD)	U	p	Cohen's d	95% Confidence Interval
AdAC Congruent Completion time	42.72 (15.86)	35.72 (9.35)	113.50	.128	.54	-2.00 – 13.00
AdAC Incongruent Error rate	1.56 (2.53)	.28 (.75)	119.00	.088	.69	.02 – 2.54
AdAC Incongruent completion time	82.28 (30.44)	60.33 (16.33)	82.00	.012	.90	5.00 – 32.00

Table L.5.

A Comparison of mean (SD) AdVIMI Motor Scores for Children with DCD and TD Matched Controls Excluding Children with Co-occurring Conditions

Measure	DCD (n =18) Mean (SD)	TD (n = 18) Mean (SD)	t(34)/ U	p	Cohen's d	95% Confidence Interval
Congruent Error rate	6.72 (2.30)	5.22 (2.58)	u 101.00	.054	.61	-.15 – 3.15
Congruent RT (msec)	32.77 (10.57)	32.54 (9.51)	t .07	.947	.02	-6.59 – 7.04
Congruent Movement Time[2]	65.52 (10.82)	55.69 (8.70)	t 3.00	.005	1.00	3.18 – 16.48
Incongruent Error rate	14.17 (6.27)	8.94 (4.29)	U 84.00	.014	.97	1.00 -9.00
Incongruent RT (msec)	42.85 (18.25)	43.80 (18.05)	t -.17	.863	-.06	-13.36 – 11.25
Incongruent Movement time[1] (msec)	93.22 (18.87)	75.09 (15.32)	t 3.16	.003	1.05	6.49 – 29.77

[2] Significant difference remained when analysing competition time

Table L.6.

A Comparison of Mean (SD) AdVIMI Verbal scores for Children with DCD and TD Matched Controls Excluding Children with Co-occurring Conditions

Measure	DCD (n = 18) Mean (SD)	TD (n = 18) Mean (SD)	U	p	Cohen's d	95% Confidence Intervals
Congruent Error	1.33 (1.61)	1.00 (1.19)	151.00	.725	.24	-1.00 – 1.00
Congruent RT	70.79 (14.17)	64.97 (7.92)	137.00	.443	.51	-1.95 – 13.60
Incongruent Error rate	5.33 (9.70)	.17 (.51)	56.00	≤.001	.75	1.00 – 3.00
Incongruent RT	83.32 (24.95)	75.55 (15.12)	140.00	.501	.38	-6.20 – 21.75

Appendix M: Further Justification for not using Statistical Corrections

Multiple comparisons within the same sample increase the family-wise error rate and therefore the likelihood of making a type I error (falsely rejecting the null hypothesis). This study is comparing groups across many variables and therefore inflating the risk of type I error. Previous research has applied corrections to statistical analysis to account for this increased risk (Field, 2013), however, debate surrounds their correct application. Whilst some argue that corrections should always be made for multiple comparisons (Ottenbacher, 1998), others argue that corrections are not required when there are clearly defined predictions (Althouse, 2016) and that corrections should be used exclusively for exploratory analysis (Armstrong, 2014; Pereger, 1998). Althouse, (2016), argues that corrections are not even necessary in exploratory analysis as long as researchers are transparent in their research methods, report all comparisons made and suggests follow-up investigation with prepared hypothesis (Althouse, 2016). Furthermore, it is suggested that the application of a correction is not appropriate when making comparisons across variables that are highly correlated (Armstrong, 2014), which is the case for many of the variables used in this research, for example the significant correlations between the BRIEF-2 parent/carer and teacher questionnaires discussed previously. The number of tests for which corrections should be adjusted for is also spurious and often debated, and the same comparison in smaller scale research could be shown to be significant when in a larger scale research project the same comparison is no longer significant. Furthermore, any corrections which are applied to this study would be incorrect and need updating if at a future date, further analysis was performed on the data set used here for publication of sub-studies or ancillary research (Althouse, 2016).

Appendix N: Full Results of Study One Including Confidence Intervals and p Values

Table N.1.

A Comparison of mean BRIEF-2 Parent/Carer Questionnaire T scores (SD) for DCD and TD Matched Controls

Measure	DCD (n = 25) Mean (SD)	TD (n = 25) Mean (SD)	t(48)/ U	p	Cohen's d	95% Confidence Intervals
Inhibit	*58.00 (8.35)*	*47.70 (8.99)*	*t 4.20*	*≤ .001*	*1.19*	*5.38 - 15.30*
Self Monitor	*56.70 (11.00)*	*47.3 (8.49)*	*t 3.36*	*.002*	*.95*	*3.76 – 15.00*
Behavioural Regulation Index (BRI)	*57.90 (8.68)*	*47.6 (9.08)*	*U 118.00*	*≤ .001*	*1.16*	*5.00 – 17.00*
Shift	*61.20 (13.10)*	*50.10 (10.10)*	*U 160.00*	*.002*	*.95*	*4.00 – 18.00*
Emotional Control	*58.50 (10.90)*	*51.70 (11.10)*	*t 2.20*	*.033*	*.62*	*.59 – 13.10*
Emotional Regulation Index (ERI)	*60.40 (11.10)*	*51.00 (9.11)*	*t 3.25*	*.002*	*.92*	*3.55 – 15.10*
Initiate	*61.50 (8.72)*	*47.20 (8.51)*	*t 5.86*	*≤. 001*	*1.66*	*9.38 – 19.20*
Working Memory	*64.50 (9.40)*	*48.80 (9.11)*	*t 5.99*	*≤ .001*	*1.69*	*10.42 – 20.90*
Plan	*63.40 (7.96)*	*48.70 (8.03)*	*t 6.51*	*≤ .001*	*1.84*	*10.12 -19.30*
Task Monitor	*64.90 (6.75)*	*46.40 (7.23)*	*t 9.38*	*≤ .001*	*2.65*	*14.58 – 22.50*
Organisation of materials	*64.20 (9.13)*	*50.30 (8.14)*	*t 5.67*	*≤ .001*	*1.60*	*8.96 – 18.80*
Cognitive regulation Index (CRI)	*65.40 (6.75)*	*48.10 (7.84)*	*t 8.37*	*≤ .001*	*2.37*	*13.16 – 21.50*
Global Executive Composite (GEC)	*66.50 (8.33)*	*49.50 (8.99)*	*t 6.92*	*≤ .001*	*1.96*	*12.03 – 21.90*

Table N.2.

A Comparison of Mean BRIEF-2 Teacher Questionnaire T scores (SD) for DCD and TD Matched Controls

Measure	DCD (n = 16) Mean (SD)	TD (n = 13) Mean (SD)	t(27) /U	p	Cohen's d	95% Confidence Intervals
Inhibit	*54.30 (9.64)*	*49.40 (13.87)*	*U 65.50*	*.094*	*.42*	*-1.00 – 15.00*
Self Monitor	*54.60 (9.71)*	*49.00 (11.20)*	*1.45*	*.158*	*.54*	*-2.33 – 13.60*
Behavioural Regulation Index (BRI)	*55.30 (10.00)*	*48.06 (12.00)*	*1.52*	*.117*	*.61*	*-1.76 – 15.00*
Shift	*59.60 (10.30)*	*50.70 (8.31)*	*2.52*	*.018*	*.94*	*1.66 - 16.20*
Emotional Control	*56.10 (13.30)*	*53.80 (13.50)*	*U 94.50*	*.68*	*.17*	*-2.00 – 11.00*
Emotional Regulation Index (ERI)	*58.00 (11.87)*	*51.50 (9.54)*	*U 63.50*	*.078*	*.59*	*-2.55 – 12.00*
Initiate	*56.30 (9.13)*	*48.50 (10.70)*	*U 54.5*	*.030*	*.79*	*7.32 – 16.00*
Working Memory	*61.30 (8.15)*	*49.40 (12.60)*	*U 44.50*	*.009*	*1.14*	*5.00 – 20.00*
Plan	*57.00 (7.75)*	*47.60 (8.48)*	*t(27) 3.11*	*.004*	*1.16*	*3.19 – 15.60*
Task Monitor	*61.40 (8.29)*	*46.20 (8.99)*	*4.71*	*≤ .001*	*1.76*	*8.55 – 21.70*
Organisation of materials	*57.30 (11.70)*	*46.40 (7.65)*	*U 40.50*	*≤ .005*	*1.08*	*3.00 – 17.00*
Cognitive regulation Index (CRI)	*60.90 (7.56)*	*47.20 (9.16)*	*U 28.00*	*≤ .001*	*1.65*	*8.00 – 21.00*
Global Executive Composite (GEC)	*60.50 (7.97)*	*48.20 (8.98)*	*3.90*	*≤ .001*	*1.96*	*5.81 -18.70*

Table N.3.

A Comparison of Mean (SD) IDS-2-EF Scores for DCD and TD Matched Controls

Measure	DCD (n = 25) Mean (SD)	TD (n = 25) Mean (SD)	t(48) /U	p	Cohen's d	95% Confidence Interval
Listing Words No. words listed	39.90 (15.20)	45.30 (12.10)	t 1.38	.174	.39	-13.20 – 2.45
Divided Attention – Animals Listed	13.80 (6.05)	19.00 (6.63)	t 2.88	.006	.81	-8.77 – -1.55
Divided Attention – Parrots crossed out	19.50 (8.27)	21.30 (9.49)	t .73	.468	.21	-6.90 – 3.22
Animal Colours Time Raw	58.70 (20.50)	44.00 (18.1)	U 163	.004	.76	5.00 – 24.30
Drawing Routes Time	23.50 (8.21)	21.90 (8.35)	t .68	.498	.19	6.31 – .19
Drawing Routes Quality	17.00 (4.95)	19.50 (5.97)	t 1.63	.111	.46	-5.64 – .60

Table N.4.

A Comparison of Mean (SD) AdFlanker Scores for DCD and TD Matched Controls

Measure	DCD (n = 25) Mean (SD)	TD (n = 25) Mean (SD)	U	p	Cohen's d	95% Confidence Intervals
AdFlanker Congruent Error rate	.76 (2.01)	.12 (.33)	296	.595	.45	-2.65 – 4.88
AdFlanker Congruent RT (Sec)	2.74 (.54)	2.31 (.15)	169	.003	1.04	.11 -. 63
AdFlanker incongruent Error rate	.56 (1.04)	.20 (.50)	260	.172	.44	-3.33 – 2.43
AdFlanker RT incongruent (Sec)	2.54 (.46)	2.26 (.18)	196	.023	.82	.02 - .44

Table N.5.

A Comparison of Mean (SD) AdAC Scores for DCD and TD Matched Controls Groups

Measure	DCD (n = 25) Mean (SD)	TD (n = 25) Mean (SD)	U	p	Cohen's d	95% Confidence Interval
AdAC Congruent Completion Time	43.80 (13.60)	38.10 (10.20)	212	.078	.51	-1.00 – 11.00
AdAC Incongruent Error rate	1.20 (2.23)	.24 (.66)	253	.126	.56	1.54 - .56
AdAC Incongruent Completion Time	82.3 (26.1)	63.8 (21.7)	162	.004	.76	8.00 – 29.00

Table N.6.

A Comparison of mean (SD) AdVIMI Motor Scores for DCD and TD Matched Controls

Measure	*DCD (n = 25) Mean (SD)*	*TD (n = 25) Mean (SD)*	*U /t(48)*	*p*	*Cohen's d*	*95% Confidence Interval*
Congruent Error rate	6.24 (2.13)	4.88 (3.26)	U 206	.038	.49	2.98 – 3.00
Congruent RT (msec)	350 (120)	330 (110)	U 289	.648	.17	-.50 - .90
Congruent Movement Time[2]	640 (110)	560 (90)	t 2.58	.013	.73	.10 – 1.30
Incongruent Error rate	14.00 (6.21)	9.40 (4.97)	t 2.92	.005	.82	1.44 – 7.84
Incongruent RT	470 (200)	430 (180)	t .74	.463	.21	-.70 – 1.40
Incongruent Movement time[1]	950 (190)	780 (170)	t 3.24	.001	.96	.70 – 2.90

[2] Significant difference remained when analysing completion time

Table N.7.

A Comparison of Mean (SD) AdVIMI Verbal scores for DCD and TD Matched Controls

Measure	DCD (n = 25) Mean (SD)	TD (n = 25) Mean (SD)	U	p	Cohen's d	95% Confidence Intervals
Congruent Error	1.28 (1.57)	.96 (1.06)	301	.813	.24	-6.20 – 1.00
Congruent RT	730 (140)	660 (80)	249	.224	.59	-.20 – 1.30
Incongruent Error rate	4.76 (8.54)	.20 (.50)	126	≤ .001	.75	1.12 - 3.00
Incongruent RT	850 (230)	770 (160)	242	.176	.43	-.20 – 1.60

Table N.8.

Descriptive Statistics for DCD and TD groups for Study Two Inhibition Measures

	DCD (n = 25)			TD (n = 25)		
Measure	*Mean*	*SD*	*Range*	*Mean*	*SD*	*Range*
Response Inhibition Measures						
AdVIMI Motor Incongruent Error rate	14.00	(6.21)	2-23	9.40	(4.97)	3-19
AdVIMI Motor Incongruent RT (Millsec)	470	(200)	149 -918	430	(180)	94.5 - 857
AdVIMI Motor Incongruent Movement Time (Millsec)	950	(190)	591 - 1260	780	(170)	495 - 1230
AdVIMI Verbal Incongruent Error rate	4.76	(8.54)	0-40	.20	(.50)	0-2
AdVIMI Verbal Incongruent RT (Millsec)	850	(230)	551 - 1600	770	(160)	490 - 1150
Interference Control Measures						
AdFlanker incongruent Error rate	.56	(1.04)	0-4	.20	(.50)	0-2
AdFlanker RT incongruent (Sec)	2.54	(.46)	1.89 – 3.72	2.26	(.18)	1.91 – 2.60
AdAC Incongruent Error Rate	1.20	(2.23)	0-9	.24	(.66)	0-3
AdAC Incongruent Completion Time (Secs)	82.3	(26.1)	46-154	63.8	(21.7)	43-137
Questionnaire						
Parent BRIEF-2 Inhibit Scale	*58.00*	*(8.35)*	41-75	*47.70*	*(8.99)*	38-69
		DCD (n=16)			TD (n = 13)	
Teacher BRIEF-2	*54.30*	*(9.64)*	39-68	*49.40*	*(13.87)*	39-85

Table N.9.

Descriptive Statistics for DCD and TD groups for Study Two Motor Measures

	DCD (n = 25)			TD (n = 25)		
Measure	*Mean*	*SD*	*Range*	*Mean*	*SD*	*Range*
MABC-2 Test Overall Score SS	4.04	(1.84)	1-7	10.40	(2.36)	8-16
MABC-2 Test Manual Dexterity SS	5.92	(3.38)	2-16	10.70	(2.48)	5-15
MABC-2 Test Aiming and Catching SS	6.04	(2.32)	2-10	10.70	(2.75)	6-16
MABC-2 Test Balance SS	4.88	(2.76)	1-12	10.00	(3.26)	6-16
IDS-2 Fine Motor Time (IDS-2-FM-T) Points	19.48	(8.56)	6-32	25.40	(7.31)	13-44
IDS-2 Fine Motor Quality (IDS-2-FM-Q) Points	19.64	(6.61)	1-29	26.70	(5.48)	12-35
IDS-2 Gross Motor (IDS-2-GM) Points	8.92	(4.81)	1-18	16.60	(4.27)	7-22
IDS-2 Visuomotor Time (IDS-VM-T) Points	45.04	(11.59)	22-64	42.70	(14.08)	12-63
IDS-2 Visuomotor Quality (IDS-VM-Q) Points	31.20	(9.67)	13-47	43.00	(11.28)	18-60

Note: SS – standard score

Appendix O: Comparisons of Parent and Teacher BRIEF-2 Responses

Significant differences were found on all scales, indexes and the global composite for the Parent BRIEF-2. However, on the Teacher BRIEF-2 significant differences were found for Shift, Initiate, Working Memory, Plan, Task Monitor and Organisation of Material Scales, the Cognitive Regulation Index and the Global Executive Composite but no significant differences were found for the Inhibit, Self Monitor or Emotional Control Scales or the Behavioural Regulation or Emotional Regulation Indexes. To investigate potential systematic variance between forms, age and gender matched pairs with data available for both the parent and teacher questionnaires were compared against each other. This sample included eight children with DCD and eight age and gender matched TD controls. Six children with DCD had no co-occurring conditions, one had ASC and one had ASC and ADHD.

Table O1 provides the means (SD) and ranges for all scales, index and the global composite for both the parent and teacher BRIEF-2 questionnaires.

Table O.1.

Mean (SD) and Range for Parent and Teacher BRIEF-2

Measure	Parent (n = 16)		Teacher (n = 16)	
	Mean (SD)	*Range*	*Mean (SD)*	*Range*
Inhibit	*53.00 (10.2)*	*38-67*	*53.00 (3.20)*	*39-85*
Self Monitor	*49.90 (7.89)*	*39-63*	*51.80 (10.1)*	*41-76*
Behavioural Regulation Index (BRI)	*52.00 (9.38)*	*39-72*	*52.40 (11.50)*	*39-75*
Shift	*55.60 (11.80)*	*39-75*	*54.30 (8.88)*	*40-73*
Emotional Control	*54.40 (10.80)*	*40-78*	*54.70 (13.40)*	*44-84*
Emotional Regulation Index (ERI)	*55.10 (9.89)*	*39-79*	*53.60 (9.51)*	*43-77*
Initiate	*53.30 (10.2)*	*38-67*	*51.00 (8.90)*	*40-72*
Working Memory	*57.80 (10.4)*	*41-72*	*55.90 (11.10)*	*38-77*
Plan	*56.30 (7.56)*	*39-66*	*52.40 (7.75)*	*40-65*
Task Monitor	*54.40 (11.7)*	*35-73*	*55.40 (11.80)*	*36-73*
Organisation of materials	*58.80 (11.00)*	*38-76*	*52.40 (10.80)*	*41-81*
Cognitive regulation Index (CRI)	*54.40 (11.70)*	*35-73*	*55.40 (11.80)*	*36-73*
Global Executive Composite (GEC)	*57.90 (9.94)*	*39-74*	*54.80 (9.21)*	*40-69*

To investigate potential differences between the forms two-way ANOVAs were performed for each of the scales and indexes which met the assumption of normality and equal variance as well as the Global Composite score. This was to assess for any potential main effects of form type or group and interaction effects between group and form type. The Shift, Initiate, Working Memory, Task Monitor, Organisation of Material, Cognitive Regulation Index and Global Composite score all meet the assumption for ANOVA. No significant main effects of form type were found indicating that Parent and Teacher ratings did not significantly differ for any of these scales, indexes or the global composite score. Main effects of group were found for the Working Memory ($F(1) = 6.06$, $p = .020$, $n^2p = .18$), Task Monitor ($F(1) = 13.23$, $p = .001$, $n^2p = .32$), Plan ($F(1) = 5.04$, $p = .033$, $n^2p = .15$) and Organisation of Materials ($F(1) = 9.34$, $p = .005$, $n^2p = .25$) Scales as well as the Cognitive Regulation Index ($F(1) = 14.74$, $p <.001$, $n^2p = .35$) and the Global Composite score ($F(1) = 10.39$, $p = .003$, $n^2p = .27$), with children with DCD reported to have significantly worse scores. No significant interaction effects were found between the groups and from type, indicating that parents and teachers did not differ significantly in how they scored each group.

Table O.2.

Correlations between Parent and Teacher BRIEF-2 Forms

Measure	r/r_s (n = 50)	p
Inhibit	$r_s = .48$	*.009*
Self Monitor	$r_s = .47$	*.010*
Behavioural Regulation Index (BRI)	$r_s =. 51$	*.004*
Shift	$r_s = .20$	*.288*
Emotional Control	$r_s =. 51$	*.004*
Emotional Regulation Index (ERI)	$r = .49$	*.007*
Initiate	$r_s = .28$	*.145*
Working Memory	$r_s = .41$	*.027*
Plan	$r_s = .64$	*≤ .001*
Task Monitor	$r_s = .68$	*≤.001*
Organisation of materials	$r_s = .52$	*.004*
Cognitive regulation Index (CRI)	$r_s = .53$	*.003*
Global Executive Composite (GEC)	$r_s = .61$	*≤ .001*

Appendix P: Relationships between Parent/Carer and Teacher BRIEF-2 Plan Scale and the IDS-2 Drawing Routes Time and Quality scores

	IDS-2 Drawing Route Time	IDS-2 Drawing Routes Quality
Parent/Carer BRIEF-2 Plan Scale	$r = .06$ ($p = .704$)	$r = .07$ ($p = .613$)
Teacher BRIEF-2 Plan Scale	$r_s = -.09$ ($p = .646$)	$r_s = -.07$ ($p = .729$)

Appendix Q: Parent/Carer BRIEF-2 Inhibit scale score for Children with a Teacher BRIEF-2 Questionnaire

Measure	DCD (n = 16) Mean (SD)	TD (n =13) Mean (SD)	t(27)	p	Cohen's d	95% Confidence Intervals
Inhibit	58.19 (7.80)	49.54 (10.26)	*2.58*	*.016*	*.96*	*1.77 – 15.53*

Appendix R: Full Results of Study Two Including Confidence Intervals and p Values

Note: Confidence Intervals have only been provided for parametric correlational analysis.

Gross Motor

Response Inhibition

Table R.1.

Correlations between the AdVIMI Response Inhibition Tasks and Gross Motor Tasks for the DCD and TD groups Combined (n = 50)

Response Inhibition	Gross Motor Measures					
	IDS-2-GM	p (95% CI)	Bal Total	p	A&C	P (95% CI)
Motor – Incongruent						
AdVIMI Motor Error	-.52[1]	≤.001 (-.70 - -.29)	- 21	.135	-.35[1]	.014 (- .57 - -.08)
AdVIMI Motor RT	- .31[1]	.030 (-.54 - -.03)	- .37	.008	-.023[1]	.87 (-.30 - -.26)
AdVIMI Motor Movement Time	- .51	≤.001	- .37	.009	- .52	<.001
Verbal – Incongruent						
AdVIMI Verbal Error	- .47	≤.001	- .42	.002	- .36	.010
AdVIMI Verbal RT	- .24	.097	- .41	.003	-.24	.101

Note: IDS-2GM = IDS-2 Gross Motor Component Point score ; Bal Total = MABC-2 Test Balance Total SS; A&C = MABC-2 Test Aiming and Catching SS; 95% CI = 95% Confidence Interval

Spearman Correlation used unless [1] present = Pearson Correlation

Interference Control

Table R.2.

Spearman correlations between Interference Control Tasks and Gross Motor Skills for DCD and TD Groups Combined (n = 50)

Interference Control	Gross Motor Measures					
	IDS-2-GM	p	Bal Total	p	A&C	p
Motor – Incongruent						
AdFlanker Error Incongruent	*- .30*	*.037*	*.04*	*.784*	*-.18*	*.225*
AdFlanker RT Incongruent	*- 51*	*≤.001*	*- .50*	*≤.001*	*-.34*	*.015*
Verbal – Incongruent						
AdAC Error Incongruent	*.04*	*.761*	*- .16*	*.275*	*.04*	*.767*
AdAC Completion Time Incongruent	*- .47*	*≤.001*	*- .44*	*.001*	*-.34*	*.015*

Note: IDS-2GM = IDS-2 Gross Motor Component point score; Bal Total = MABC-2 Test Balance Total SS; A&C = MABC-2 Test Aiming and Catching SS

Questionnaire

Table R.3.

Correlations, for DCD and TD groups combined, between Gross Motor Measures and the BRIEF-2 Parent (n = 50) and Teacher (n =29) Inhibit Scale

BRIEF-2 Inhibit Scale	Form	Gross Motor Measures					
		IDS-2-GM	*p*	*Bal Total*	*p (95% CI)*	*A&C*	*p*
Inhibit	Parent (n = 50)	*- .47*	*≤.001*	*- .49*[1]	*≤.001 (-.68 - -.25)*	*- .41*	*.003*
Inhibit	Teacher (n = 29)	*-. 36*	*.054*	*-.02*	*.904*	*- .08*	*.662*

Note: IDS-2GM = IDS-2 Gross Motor Component point score; Bal Total = MABC-2 Test Balance Total SS; A&C = MABC-2 Test Aiming and Catching SS; 95% CI = 95% Confidence Interval

Spearman Correlation used unless [1] present = Pearson Correlation

Fine Motor Skills

Response Inhibition

Table R.4.

Relationships between Response Inhibition Tasks and Fine Motor Measures for DCD and TD Groups Combined (n = 50)

Response Inhibition	Fine Motor Measures					
	MD	p (95% CI)	IDS-2-FM-T	p (95% CI)	IDS-2-FM-Q	p (95% CI)
Motor – Incongruent						
AdVIMI Motor Error	-.60[1]	*<.001 (-.76 - -.39)*	*- .44$_{1}$*	*.001 (-.64 – -.18)*	*- .34*	*.015*
AdVIMI Motor RT	.08	*.568*	*- .18*	*.222*	*- .22*	*.116*
AdVIMI Motor Movement Time	-.34	*.018*	*- .30*	*.036*	*- .20*	*.172*
Verbal – Incongruent						
AdVIMI Verbal Error	.52***	*<.001*	*- .28*	*.046*	*- .46*	*≤.001*
AdVIMI Verbal RT	.07	*.652*	*- .25*	*.085*	*- .16*	*.256*

Note: MD = MABC-2 Test Manual Dexterity SS; IDS-2-FM-T = IDS-2 Fine Motor Time point score; IDS-2-FM-Q = IDS-2 Fine Motor Quality point score; 95% CI = 95% Confidence Interval

Note: Spearman Correlation used unless $_{1}$ present = Pearson Correlation

Interference Control

Table R.5.

Spearman Correlations between Interference Control Tasks and Fine Motor Measures for DCD and Without Groups Combined (n = 50)

Interference Control	Fine Motor Measures					
	MD	p	IDS-2-FM-T	p	IDS-2-FM-Q	p
Motor – Incongruent						
AdFlanker Error Incongruent	-.26	*.065*	*.07*	*.609*	*- .10*	*.469*
AdFlanker RT Incongruent	-.20	*.175*	*- .33*	*.019*	*- .22*	*.123*
Verbal – Incongruent						
AdAC Error Incongruent	-.09	*.530*	*- .29*	*.040*	*- .21*	*.135*
AdAC Completion Time Incongruent	-.32	*.025*	*- .44*	*.001*	*- .31*	*.028*

Note: MD = MABC-2 Test Manual Dexterity SS; IDS-2-FM-T = IDS-2 Fine Motor Time point score; IDS-2-FM-Q = IDS-2 Fine Motor Quality point score

Questionnaires

Table R.6.

Correlations, for DCD and TD Groups Combined, between Fine Motor Measures and the BRIEF-2 Parent (n = 50) and Teacher (n =29) Inhibit Scale

BRIEF-2 Inhibit Scale	Form	Fine Motor Measures					
		MD	*p*	*IDS-2-FM-T*	*p*	*IDS-2-FM-Q*	*p*
Inhibit	Parent (n = 50)	*-.33*	*.02*	*-.27*	*.060*	*-.50*	*≤.001*
Inhibit	Teacher (n = 29)	*-.43*	*.02*	*-.10*	*.597*	*-.32*	*.090*

Note: MD = MABC-2 Test Manual Dexterity SS; IDS-2-FM-T = IDS-2 Fine Motor Time point score; IDS-2-FM-Q = IDS-2 Fine Motor Quality point score

Spearman Correlation used unless $_1$ present = Pearson Correlation

Drawing Skills

Response Inhibition

Table R.7.

Relationships between Response Inhibition Tasks and Drawing Tasks for DCD and TD Groups Combined (n = 50)

Response Inhibition	Drawing Measures			
	IDS-2-VM-Q	p (95% CI)	IDS-2-VM-T	p
Motor – Incongruent				
AdVIMI Motor Error	*-.53*	*≤.001*	*-.20*	*.163*
AdVIMI Motor RT	*.01*[1]	*.966* (*-.28 - .27)*	*-.12*	*.395*
AdVIMI Motor Movement Time	*-.25*	*.075*	*-.12*	*.403*
Verbal – Incongruent				
AdVIMI Verbal Error	*-.33*	*.019*	*.08*	*.579*
AdVIMI Verbal RT	*-.11*	*.455*	*-.14*	*.325*

N*ote:* IDS-2-VM-Q IDS-2 Visuomotor Quality point score; IDS-2-VM-T IDS-2 Visuomotor Time point score

Spearman Correlation used unless [1] present = Pearson Correlation

Table R.8.

Spearman Correlations between Interference Control Tasks and Drawing Measures for DCD and TD Combined (n = 50)

Interference Control	*Drawing Measures*			
	IDS-2-VM-Q	*p*	*IDS-2-VM-T*	*p*
Motor – Incongruent				
AdFlanker Error Incongruent	*-.15*	*.312*	*.13*	*.364*
AdFlanker RT Incongruent	*-.32*	*.024*	*-.12*	*.390*
Verbal – Incongruent				
AdAC Error Incongruent	*-.10*	*.481*	*-.23*	*.115*
AdAC Completion Time Incongruent	*-.26*	*.066*	*-.19*	*.178*

Note: IDS-2-VM-Q = IDS-2 Visuomotor Quality point score; IDS-2-VM-T = IDS-2 Visuomotor Time point score

Questionnaire

Table R.9.

Spearman Correlations, for DCD and TD groups Combined, between Drawing Measures and the BRIEF-2 Parent (n = 50) and Teacher (n =29) Inhibit Scale

BRIEF-2 Inhibit Scale	Form	Drawing Measures			
		IDS-2-VM-Q	*p*	*IDS-2-VM-T*	*p*
Inhibit	Parent (n = 50)	*-.45*	*.001*	*0.00*	*.979*
Inhibit	Teacher (n = 29)	*-.11*	*.579*	*.01*	*.966*

Note: IDS-2-VM-Q = IDS-2 Visuomotor Quality point score; IDS-2-VM-T = IDS-2 Visuomotor Time point score

Overall Motor Skills

Response Inhibition

Table R.10.

Correlations between the AdVIMI Response Inhibition Tasks and Overall Motor Tasks for the DCD and TD groups Combined (n = 50)

	MABC-2 Total	p (95% CI)
Motor – Incongruent		
AdVIMI Motor Error	*-.48*[1]	*≤.001 (-.67 - -.24)*
AdVIMI Motor RT	*-.11*	*.461 (-.37 - .18)*
AdVIMI Motor Movement Time	*-.37*	*.009*
Verbal – Incongruent		
AdVIMI Verbal Error	*-.55*	*≤.001*
AdVIMI Verbal RT	*-.17*	*.239*

Note: 95% CI = 95% Confidence Interval

Interference Control

Table R.11.

Spearman Correlations between Interference Control Tasks and Overall Motor skills Measures for DCD and TD groups Combined (n = 50)

	MABC-2 Total	p
Motor – Incongruent		
AdFlanker Error	*-.21*	*.152*
AdFlanker RT	*-.37*	*.009*
Verbal – Incongruent		
AdAC Error	*-.14*	*.316*
AdAC Completion Time	*-.47*	*≤.001*

Questionnaire

Table R.12.

Correlations, for DCD and TD groups Combined, between Overall Motor Measures and the BRIEF-2 Parent (n = 50) and Teacher (n =29) Inhibit Scale

	Form	MABC-2 Total	p
Inhibit	*Parent (n = 50)*	*-56*	*<.001*
Inhibit	*Teacher (n = 29)*	*-.23*	*.238*