MOTOR COORDINATION IN CHILDREN: DETERMINANTS, SCREENING AND INTERVENTION

by

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INTELLECTUAL PROPERTY AND PUBLICATIONS

The candidate confirms that the work submitted is his/her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

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The candidate was solely responsible for the production of the content. Dr Snapp-Childs and Dr Kountouriotis programmed the intervention trials. Other named authors provided support through review and modification only.

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ABSTRACT

There is little doubt that a large number of children suffer from problems performing movements, and that these problems have a huge impact on many aspects of their lives. However, there are issues surrounding the identification and measurement of these difficulties. Chapter 2 of this thesis explores this in a large group of children (n=448 children, 4-11 years old), and shows that there is only limited association between children's functional motor performance, performance on a traditional measure of motor activities, and their performance in real life situations. The measure of sensorimotor functional performance was then used to explore relations that had previously been linked to motor ability on the basis of activity measures. In Chapter 3, the links between sensorimotor function and obesity were explored in a prospective cohort of 820 4-5 year old children. No relation was found at this age. Chapter 4 examined the relation between sensorimotor control and academic attainment, in a cross-sectional sample of 381 children in primary school (age 5-11). A relation was observed between sensorimotor control and school attainment levels for mathematics, reading and writing, indicating a possible route for intervention. Building on these results, one method that has the potential to target these sensorimotor functions is the use of haptic robotic devices. This was explored in Chapter 5 in a cross-over intervention study with 51 children aged 5-11years. However, no transfer of benefit could be seen to the sensorimotor tasks. Therefore, an alternative method of intervention was explored in Chapter 6, with the aim to create an intervention to target children with handwriting difficulties. Results from the feasibility study, implemented with 515 children across 10 primary schools, suggested that with a few alterations interventions could be run autonomously in schools.

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LIST OF ABBREVIATIONS

ABD	Atypical Brain Development
ADHD	Attention Deficit Hyperactivity Disorder
ALSPAC	Avon Longitudinal Study of Parents and Children
AS	Asperger's Syndrome
ASD	Autism Spectrum Disorder
BCS	British Birth Cohort Study
BiB	Born in Bradford
BMI	Body mass index
BOTMP	Bruininks-Oseretsky Test of Motor Proficiency
CKAT	Clinical Kinematic Assessment Tool
CO-OP	Cognitive Orientation to Daily Occupational Performance
DAMP	Deficits in Attention, Motor and Perceptual abilities
DASH	Detailed Assessment of Speed of Handwriting
DCD	Developmental Coordination Disorder
DCDQ	Developmental Coordination Disorder Questionnaire
DSM	Diagnostic and Statistical Manual
EACD	European Academy for Childhood Disability
ECLS-K	Early Childhood Longitudinal Survey– Kindergarten
ESI-R	Early Screening Inventory–Revised
ICF	International Classification of Functioning, Disability and Health
KS2	Key Stage 2
LAP-D	Learning Accomplishment Profile–Diagnostic
MABC	Movement Assessment Battery for Children

MAND	McCarron Assessment of Neuromuscular Development
NLSY	National Longitudinal Survey of Youth
NTT	Neuromotor Task Training
Ofsted	Office for Standards in Education, Children's Services and Skills
SENCO	Special educational needs coordinators
SIT	Sensory Integration Therapy
SLI	Specific Language Impairment
TA	Teaching assistant
VMI	Beery-Buktenica Developmental Test of Visual-Motor Integration
VP	Visual perception
WHO	World Health Organisation

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Every interaction that humans have with the world is through movement: from eye movements generated to acquire new visual information, to gripping a pen and moving the hand in order to write. The ability to learn new movements, and to adapt previously learned movements in a variable environment, underpins our success as a species. It is therefore unsurprising that negative consequences are often observed in multiple domains when children have difficulties with performing motor actions. These children were traditionally labelled as 'clumsy' or 'awkward' and it was assumed that they would grow out of their difficulties (Missiuna, Gaines, & Soucie, 2006). However, it is now recognised that these children often continue to struggle through childhood, adolescence and adulthood (Cousins & Smyth, 2003; Missiuna, Moll, King, Stewart, & Macdonald, 2008; Stephenson & Chesson, 2008; Tal-Saban, Zarka, Grotto, Ornoy, & Parush, 2012). To reflect this, a number of clinical diagnostic labels, indicating developmental motor problems, have been used including 'Nonverbal Learning Disorder', 'Deficits in Attention, Motor and Perceptual abilities (DAMP)', 'Clumsy Child Syndrome', 'Minimal Brain Dysfunction', and 'Dyspraxia' (Gibbs, Appleton, & Appleton, 2007), all with overlapping criteria. However, the label that has gained the most traction when describing children with poor motor performance is Developmental Coordination Disorder (DCD) (Blank, Smits-Engelsman, Polatajko, & Wilson, 2012; Gibbs et al., 2007; Sugden, 2006). This chapter begins by reviewing the current literature on DCD, and identifies some of the many challenges relating to the assessment and diagnosis of motor difficulties.

1.2 Developmental Coordination Disorder (DCD)

1.2.1 Clinical diagnostic criteria

DCD is a neurodevelopmental disorder, diagnosed on the basis of symptoms but not aetiology (Sugden, 2006). This diagnosis was defined in the Diagnostic and Statistical Manual (DSM) Fourth Edition Text Revision (DSM-IV TR) (American Psychiatric Association, 2000) according to the following criteria:

> *"(A) Performance in daily activities that require motor coordination is substantially below that expected given the person's chronological age and measured intelligence. The disorder may be manifested by marked delays in motor milestones (e.g. walking, crawling, sitting), dropping things, by 'clumsiness' and by poor performance in sports or poor handwriting.*
>
> *(B) The disturbance described in criterion A significantly interferes with academic achievement or activities of daily living.*
>
> *(C) The disturbance is not due to a general medical condition (e.g. cerebral palsy, hemiplegia, or muscular dystrophy) and does not meet criteria for a pervasive developmental disorder.*
>
> *(D) If mental retardation is present, motor difficulties are in excess of those usually associated with mental retardation."*

In the Leeds Consensus Statement (Sugden, 2006), it was agreed that the child should perform below the 5th percentile on an 'appropriate, norm-referenced test of general motor competence' in order to satisfy Criterion A. Scores under the 15th percentile can be used as the cut-off point at which to monitor children for potential difficulties. Criterion A was further clarified in the European Academy for Childhood Disability (EACD) guidelines (Blank et al., 2012), with a recommendation to use a valid, standardised, objective and norm referenced test. However, no one 'gold-standard' measure for this was given. Instead, the two most commonly used screening tools were identified and evaluated – the Movement Assessment Battery for Children (MABC) (Henderson & Sugden, 1992), and the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Bruininks, 1978). The MABC, and the MABC Second Edition (MABC-2) (Henderson, Sugden, & Barnett, 2007) are norm-referenced tests involving 32 tasks across three subsections: manual dexterity, aiming and catching and balance. Each subsection measures performance on a number of tasks, which change slightly according to the child's age-band. For example, on the MABC-2, children aged 3-6 years complete three manual dexterity tasks involving: posting coins in a box, threading beads on a string, and a path tracing task. The aiming and catching subsection involves catching a beanbag and throwing it onto a target, and the balance subsection involves standing on one leg (completed on both left and right legs), walking along a line with heels raised, and jumping along a series of mats. For children aged 7-10 years, the tasks are adapted to be more difficult. For example, the manual dexterity tasks involve placing pegs, threading string through a series of holes, and a more difficult tracing task than used in the younger age group. Each item is rated on a six-point scale, and then standardised. Percentile scores can be calculated for each subsection individually, and for the MABC as a whole.

The BOTMP, and the BOTMP second edition (BOT-2) (Bruininks & Bruinicks, 2005) are the other standardised assessments discussed in the EACD guidelines. The BOT-2 involves 53 items assessing: fine motor precision (7 items), fine motor integration (8 items), manual dexterity (5 items), bilateral coordination (7 items), balance (9 items), running speed and agility (5 items), upper limb coordination (7 items), and strength (5 items). All items are scored on scales of 0-1 to 0-12, and standardised scores are collapsed into composite areas: fine manual control, manual coordination, body coordination, and strength and agility, as well as an overall score. Although the BOTMP and the MABC are by no means the only assessments used, these two tests were recommended within the EACD guidelines in the absence of a 'gold-standard' measure to satisfy Criterion A of the DSM-IV TR.

To comply with Criterion B, the EACD guidelines recommend using a validated questionnaire, such as the MABC Checklist (Henderson & Sugden, 1992), or the Developmental Coordination Disorder Questionnaire (DCDQ) (Wilson, Dewey, & Campbell, 1998). These questionnaires both ask a range of questions about the abilities of the child in certain 'real-life' situations, with the MABC Checklist designed for completion by teachers, and the DCDQ designed for completion by parents.

It is recommended by the EACD guidelines that compliance with Criterion C and D should be assessed by a clinician, in order to rule out neurological, medical and behavioural dysfunction that would explain the poor motor performance.

Although the clinical requirements for this diagnosis are such that a child must meet all four of the criteria, in the research literature it is often found that only Criterion A is discussed. Gueze, Jongmans, Schoemaker, and Smits-Engelsman (2001) identified 41 publications that had classified one experimental group as having DCD. However, although 74% of these based their classifications on fulfilling Criterion A, only 60% made any mention of whether Criterion B was fulfilled, and a third did not exclude cases on the basis of Criterion C or D. Smits-Engelsman, Schoemaker, Delabastita, Hoskens, and Geuze, (2015) repeated this analysis following the new criteria for DCD as stated in the DSM fifth edition (DSM-5) (American Psychiatric Association, 2013):

> *"(A) The acquisition and execution of coordinated motor skills is substantially below that expected given the individual's chronological age and opportunity 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 vocational activities, leisure, and play.

(C) Onset of symptoms is in the early developmental period.

(D) The motor skills deficits are not better explained by intellectual disability (intellectual developmental disorder) or visual impairment and are not attributable to a neurological condition affecting movement (e.g., cerebral palsy, muscular dystrophy, degenerative disorder)."

Again, whilst 85% of the studies complied with the new Criterion A, only 38% reported if or how Criterion B was assessed. In 41% of the studies there was no mention of Criterion C, and in 62% there was no mention of Criterion D.

1.2.2 Prevalence

This lack of clarity regarding diagnoses predictably impacts on the estimated prevalence of DCD. The most commonly cited prevalence rate for DCD is 5-6% of the population. However, estimates based on different criteria have varied. Tsiotra et al. (2006) reported a prevalence of DCD of 8% in a sample of Canadian children (n = 591, mean age 11.46 years), and 19% in a sample of Greek children (n = 269, mean age = 11.3 years) when they used a criterion of scoring under the 12th percentile on the BOTMP short form (Bruininks, 1978). These difference were ascribed to lifestyle differences. Wright and Sugden (1996) cited prevalence rates of 3.4% of UK children scoring below the 5th percentile on the MABC, and the MABC Checklist, or 5% scoring under the 10th percentile, and prevalence rates of about half this amount in a group of children in Singapore assessed in the same way.

Prevalence has also been examined in two large cohort studies. Firstly, in a large cohort of 33354 Danish children, aged 7 years, Faebo Larsen, Hvas Mortensen, Martinussen, and Nybo Andersen (2013) identified a prevalence rate of DCD (using the DCDQ) at 3.6% in those born post-term, 2.9% of the term-born children, 6.4% of the pre-term children, and 18.3%

of the very preterm children. In a cohort of 6902 children in the Avon Longitudinal Study of Parents and Children (ALSPAC) study, 5% of the children (aged 7-9 years) met the criteria for probable DCD on the MABC (< 15^{th} percentile).

However, Lingam, Hunt, Golding, Jongmans, and Emond (2009) point out that in many studies, not all of the criteria for DCD were assessed. In their own study of 7256 children aged 7-8 years old in the UK, 4.9% fulfilled the criteria for 'probable DCD' (scoring < 15^{th} percentile on the MABC), and 1.8% fit all criteria for DCD (<5^{th} percentile). These inconsistencies in measurement scores, cut-off points and whether all criteria are fulfilled make it difficult to compare between studies.

1.2.3 Heterogeneity

The other main reason for the differing prevalence is that depending on the assessment measure used, very different children may be identified as showing difficulties. DCD is often described in the literature as a heterogeneous disorder, with many children showing very different levels of ability depending on the task. To illustrate this, Haga, Pedersen, and Sigmundsson (2008) completed the MABC with 91 children aged 4-5 years from the general population, and found that the largest correlation between any two item scores was .31, with most *r* values falling between .12 - .19. Likewise, when two different screening assessments are used, different children are often identified as showing difficulties. In a group of 69 children (mean 11.6 years old) who completed the BOTMP, the MABC and the DCDQ, Kaplan, Wilson, Dewey, and Crawford (1998) found that within a group of 10 children diagnosed with DCD (using cut-off points equivalent to the 15^{th} percentile), 30% met the DCD criteria on only one of the measures, 60% met the criteria on two of the tests, and 10% met the DCD criteria on all three of the tests.

A number of studies have examined the issue of heterogeneity through cluster analysis within samples identified as having DCD. Dewey and Kaplan (1994) found three cluster types of motor difficulties (assessed by an occupational therapist on a number of motor and sensory integration tests) within a group of children (n = 102, aged 6-10 years). One group had difficulties in balance, coordination and gestural performance, one group showed deficits in motor sequencing, and one group showed difficulties in all of these areas. Hoare (1994) examined a group of 80 children (aged 6-9 years) on the McCarron Assessment of Neuromuscular Development (MAND) (McCarron, 1982), which involved ten items such as placing beads in a box, grip strength, balancing on one foot and heel-toe walking. Hoare identified five subtypes where children had good balance, good visual-motor performance, generalised perceptual dysfunction, good kinaesthetic ability and motor execution problems.

Wright and Sugden (1996b) examined a group of 69 children aged 6-9 years old who had scored below the 15th percentile on the MABC Checklist and on the full MABC battery. After running a factor analysis on the MABC and checklist raw scores, and then a cluster analysis, they identified a number of different 'subtypes' within the sample. Although one of these groups scored consistently poorly on all of the measures, other groups only showed difficulties with, for example, catching or manual difficulties. More recently, Macnab, Miller, and Polatajko (2001) examined a sample of 62 children, clinically diagnosed with DCD based on the 15th percentile of the BOTMP. A number of assessments were completed with these children, including the manual dexterity pegboard task and the running speed measure from the BOTMP, and the standing balance subtest of the MAND. The cluster analysis revealed five subtypes: good balance, good visual-motor, general perceptual-motor problems, poor fine/visual motor and poor gross motor.

This heterogeneity has particular implications for the identification of children with difficulties. Wright and Sugden (1996b) point out that many of the children who show severe motor difficulties, but only in one area, may not be diagnosed with DCD if an overall composite score is used, or if the assessment used does not include the particular area they have difficulties with. This is explored further in Chapter 2.

1.2.4 Comorbidity

There is also strong evidence that DCD frequently presents with other disorders and difficulties. For example, in the ALSPAC cohort (Lingam et al., 2010), the 346 children identified as having probable DCD were found to have an increased risk of having attention, reading, spelling, social and non-verbal problems.

The most commonly cited comorbid disorder with DCD is Attention Deficit Hyperactivity Disorder (ADHD). Kadesjö and Gillberg (1999) found that in their sample of children with either severe or moderate DCD, 19% met the full crieria for ADHD, and 47% had five or more ADHD symptoms. Pitcher, Piek, and Hay (2007) examined 104 male children (age 7-12 years) who had been diagnosed with ADHD, and found that their scores on the MABC were significantly worse than a group of 39 control children, and that between 28.9-42% of the children with ADHD scored under the 5th percentile on the MABC (depending on ADHD subtype), compared to 10.3% of children in the comparison group. Similarly, Watemberg, Waiserberg, Zuk, and Lerman-Sagie (2007) found that in 96 patients (average age 8 years) attending a paediatric neurology clinic and diagnosed with ADHD, 55.2% also scored under the 5th percentile on the MABC. In fact, in Nordic countries a diagnosis of Deficits in Attention, Motor control, and Perception (DAMP) is often given (Gillberg, 2003), rather than separate DCD/ADHD diagnoses, as the co-occurrence of attention and motor deficits is so common.

Another frequently co-occurring diagnosis with DCD is language disorder. In a review by Hill (2001) on motor disorders in Specific Language Impairment (SLI), the prevalence of DCD (classified by a score of < 15th percentile on the MABC) in children with SLI was found to be between 40-90%. Likewise, Archibald and Alloway (2008) found that scores on language tasks (including sentence recall and narrative skills) in 11 children who scored < 15th percentile on the MABC were almost identical to a clinical group of children with SLI. Mirroring this finding, performance on the MABC was significantly worse than a group of control children in a group of thirty five 9-10 year old children diagnosed with SLI (Finlay & McPhillips, 2013). Interestingly, the children in the SLI group also performed significantly worse on the MABC than a group of children who also had comparable language difficulties, but had not been clinically diagnosed with SLI. This finding suggests that the co-occurring difficulties may have compounded the problems experienced by these children.

Autism spectrum disorders (ASD) has also been found to have a high co-morbidity rate with DCD. In a study of 131 girls with clinically diagnosed ASD, DCD was also diagnosed in 25% of children in the school aged group (7-18 years), and 80% of the preschool group (3-6 years). In a study examining 11 children with Asperger's syndrome (AS) (diagnosed by a consultant paediatrician), and 9 children with clinical movement problems (< 15^{th} percentile on the MABC), it was found that all the children with AS exhibited motor impairment to an extent that would qualify them for a comorbid diagnosis if this were allowed under DSM criteria (Green et al., 2002).

Although these studies highlight just how common comorbid difficulties are in children with DCD, it should be noted that many other studies tend to not screen for these other disorders, simply stating that participants meet the diagnostic criteria for DCD.

1.2.5 Aetiology and neurobiology

The co-occurrence of these disorders have led some to question the value of these discrete classifications and whether, instead, these classifications are based on deficits of overlapping or contiguous neural systems. One account that builds on this notion is the suggestion of 'atypical brain development' (ABD) (Gilger & Kaplan, 2001; Kaplan, Wilson, Dewey, & Crawford, 1998). This account takes the view that all developmental disorders are due to variations in the development of the brain, including problems with the activation of certain areas. The more diffuse this disruption, the more severe and widespread the resulting difficulties. In contrast, 'pure' cases of DCD or ADHD for example, would only occur when this disruption occurs in specific areas that are not likely to overlap.

There is indeed considerable overlap in the neural pathways of cognitive and motor systems which, if disturbed, would be consistent with this interpretation (Diamond, 2000). Diamond highlighted evidence from neuroimaging studies showing that areas in the cerebellum and basal ganglia activated during motor tasks are also activated along with the prefrontal cortex during cognitive tasks. In particular, the neocerebellum has been shown to be involved in motor learning. Firing in this area peaks when the motor task is novel, and this activation pattern gradually decreases with task familiarity (Thach, 1998). This same pattern of activation is seen in cognitive tasks (Diamond, 2000).

Likewise, the neural development of motor and language systems are intertwined. Iverson (2010) presented evidence regarding the links between motor development and the emergence of language and communication. For example, increased rhythmic motor stereotypies coincide with the onset of regular, rhythmically timed babble at around 28 weeks (Koopmans-van Beinum & van der Stelt, 1986). Iverson postulates that motor skills allow the practice of the organised tightly timed actions required for babbling. Therefore delays or deficits in developing these motor skills would in turn constrain language and other learning opportunities. Pulvermüller and Fadiga (2010) also point out that language processing is based on the neural circuits responsible for connecting ‘action’ and ‘perception’ systems.

Other neural areas have been implicated in cases of DCD. Zwicker, Missiuna, Harris, and Boyd (2010) examined the brain activation of 7 children (mean age 10 years) who had scored under the 15th percentile on the MABC, and 7 age matched controls, whilst they were performing a flower tracing task. The children with DCD showed greater activation in the dorsolateral prefrontal cortex (an area linked to attentional control), suggesting they required more concentration to complete the task. They also showed greater reliance on areas associated with visual and spatial processing, suggesting they relied more on vision to guide their movements. In comparison, the typically developing subjects showed greater activation in the precuneus, and the left superior and inferior frontal gyri, areas associated with spatial processing, and the postcentral gyrus and insula regions involved in error processing. Overall, more activation was seen for the DCD children, indicating it took more effort to achieve the same motor performance for these children. Similarly, Licari et al. (2015) examined the brain activation of 13 children with DCD (aged 8-10 years, scoring < 5^{th} percentile on MABC), and 13 controls matched for age, whilst performing a sequential finger touching task, and a repetitive hand clenching task. Decreased activation in the left superior frontal gyrus was observed, consistent with the abnormal function seen in Zwicker et al. (2010), and again highlighting the potential role of executive processing skills.

1.2.6 Sensorimotor and cognitive deficits

In order to examine the functional difficulties in processing that may result from abnormal neural activations, researchers have examined whether specific sensorimotor and cognitive processes are affected in DCD. A large range of specific sensorimotor and cognitive processing deficits have been postulated as being important within DCD. Firstly, it has been argued that children with DCD may have impairments with online control of movements. For example, Hyde and Wilson (2011) found that 13 children (aged 8-12 years) with DCD (scoring <10^{th} percentile on the MAND), were slower to correct their trajectories in double-jump aiming tasks, indicating an impairment in rapid online control. They were also relatively more affected by this task than controls in terms of overall movement time, indicating these children were not as efficient at using an internal error feedback (ascribed to a failure to update their forward models). Likewise, Wilmut, Wann, and Brown (2006) found that a group of 7 children (aged 7 years, scoring < 10^{th} percentile on the MABC) from a school population were slower than a group of 10 controls in these double-step conditions (but not in the single-step ones). Eye tracking revealed that this may have been due to the propensity of these children to fixate for longer on the target before making the movement, therefore, relying heavily on online visual feedback whilst taking longer to utilise visual information. However, Plumb et al. (2008) saw no difference between performance in perturbed and non-perturbed aiming conditions in a group of 22 children with DCD (mean age 9 years, <1^{st} percentile on MABC) from a clinical population and controls, and rather than deficits with online correction. Plumb et al. (2008) suggested that children with DCD may be impaired in using error signals or may have difficulties transmitting forward motor commands.

These types of feedforward deficits have also been observed in eye movements (Langaas, Mon-Williams, Wann, Pascal, & Thompson, 1998). A group of eight children (aged 5-7 years), who had scored below the 5^{th} percentile on the MABC, and who had shown widespread problems on the MABC checklist (as well as 24 controls aged 5-7 years, and 8 adult controls), were instructed to fixate their eyes on a dot of light which followed a sinusoidal trajectory. Their eye movements were then tracked. For pursuit movements, the control children and adults did not significantly differ. However, the children with DCD had significantly poorer gain, with none of the children's performance falling within the 95% confidence intervals for their age group. Furthermore, the children with DCD (and the group born prematurely) exhibited larger unsigned pursuit lags, indicating that although these groups were attempting to use the predictive tracking necessary for pursuit movements, their predictive models were less refined, and therefore their eye movements were less synchronous with the target than the controls. In a recent review of this area, Wilson, Ruddock, Smits-Engelsman, Polatajko, and Blank (2013) concluded that there is indeed converging evidence that children with DCD may have a core deficit in forward (predictive) control.

These control deficits may be due to the timing of visual information that is available regarding future targets. Using a simple tracking task, de Oliveira and Wann (2010) showed that 14 adolescents and young adults with DCD (aged 15-27 years, < 16^{th} percentile on MABC when aged 10 years, and in current study) had difficulty integrating information about near and far track direction. However, they could complete the task as well as controls when only short timescale track direction information was present (500ms). In a follow up study, de Oliveira, Billington, and Wann (2014) expanded on this, finding that 11 adolescents/adults with DCD (aged 16-26 years, diagnosed as in previous study), found that children with DCD could use online control, if visual information was available for the subsequent 500-750ms. Any more information than this was actually counterproductive. This again led to the conclusion that children with DCD found it difficult to integrate distal preparatory visual information with the information that is revealed when performing the movement itself. In addition, the fact that the children with DCD also performed more poorly when very short temporal information was available, suggests that children with DCD may only effectively be able to use online visual control in limited timeframes.

Children with DCD have shown other visual deficits as well. Sensitivity to looming information (the discrete changes in optical size) is a skill that develops through childhood (Wann, Poulter, & Purcell, 2011). Children with DCD show developmentally immature looming detection, below that expected for their age (Purcell, Wann, Wilmut, & Poulter, 2012). Mon-Williams, Wann, and Pascal (2007) also found that children with DCD (n = 8, aged 5-7 years, <5th percentile on MABC plus problems on all four MABC checklist areas) had particular difficulty when cross-modal judgements required the use of visual information to be integrated with kinaesthetic information to guide judgements about their limb positions.

Postural stability control has also found to be affected in children with DCD. Wann, Mon-Williams, and Rushton (1998) used a 'swinging room' paradigm to show that within a group of six children with DCD (aged 10-12 years, <5th percentile on MABC), some children were dependent on vision as a source of postural information (similar to a group of nursery children aged 3-4 years). However, two of the DCD children, who had scored <5th percentile on the MABC overall, but not on the balance subsection individually, did not show these deficits. Again, the authors comment on the heterogeneity of children under the DCD label. Laufer, Ashkenazi, and Josman (2008) examined the centre of pressure (COP) displacement of a group of 26 children with DCD (mean age 5 years, <13th percentile on the MABC) and age matched controls, whilst performing a concurrent cognitive naming task. Children with DCD showed higher COP sway, and more variable sway than the controls. They also showed significantly worse performance in the dual-task conditions in their sway, seemingly prioritising the cognitive elements of the task.

These postural control deficits may influence gait. Deconinck et al. (2006) found that a group of 10 children with DCD (mean age 7 years, <15th percentile on MABC) exhibited shorter steps at a higher frequency than age matched controls, demonstrating a 'safer' but less efficient walking strategy. With the same sample of children with DCD, Rosengren et al. (2009) also demonstrated greater variability and greater asymmetry in the gait movement patterns than ten age matched controls. It was suggested that these patterns could be due to poor postural and balance control.

Other forms of locomotion may also be affected. De Oliveira and Wann (2011, 2012) performed two experiments examining the driving performance of adolescents and young adults who had been diagnosed with DCD when young, and still scored < 16th percentile on the MABC. It was found that compared to the control children, the children with DCD made more adjustments to the steering wheel and showed larger variance in heading when driving along straight roads (de Oliveira & Wann, 2011) and around bends (de Oliveira & Wann, 2012). In addition, the DCD population took 50% as long as the controls to react to pedestrians walking towards their path, and concurrent auditory distraction had a more detrimental effect on reaction times for the children with DCD than for the controls.

A number of deficits in the cognitive domain have also been linked to DCD. The role of executive function and attention has frequently been examined in children with DCD following comorbidity and neuroimaging studies suggesting these domains may be affected. Piek, Dyck, Francis, and Conwell (2007) examined 138 typically developing children aged 6-14 years, 18 children who had previously been diagnosed with DCD (<5th percentile for MABC), 20 with ADHD (predominantly inattentive subtype) and 19 with ADHD (combined hyperactive/impulsive and inattentive subtype). The children with DCD were found to perform more poorly than either the controls or the ADHD groups on a number of assessments of executive function and working memory. Specifically, there was a trend that the children were slower in their reaction times and in completing the tasks generally. The authors concluded that the children with DCD may have poorer visuospatial ability, so they take longer to process the necessary information for the task, but can then execute it successfully.

1.2.7 Secondary Consequences

The broad nature of the deficits in processing seen in children with DCD means it is of little surprise that these children have been shown to suffer a range of negative consequences in multiple domains. Missiuna, Moll, King, King, and Law (2007) have described a trajectory for these secondary issues, whereby motor and play concerns in the early years develop into self-care and academic problems at primary school, as well as problems interacting with peers. This in turn leads to mental health issues such as depression and anxiety in later childhood and teenage years.

In the physical domain, children with DCD have been found to show lower levels of physical activity than their peers, as concluded in a systematic review by Rivilis et al. (2011), who found this result in 20 out of 21 studies examining this link. In the same review, evidence was provided that children with DCD have poorer cardiorespiratory fitness, poorer muscle strength, and poorer anaerobic capacity. For example, Schott, Alof, Hultsch, and Meermann (2007) examined 123 children (aged 4-12 years) with DCD (<5th percentile on MABC) or probable DCD (<15th percentile on MABC), against 106 age matched controls. Fitness on running, jumping, throwing and strength tests were all worse than the controls in the 10-12 year olds, and sprinting ability was worse in children with DCD aged 4-6 years. One possible link that has been put forward to explain this, is that these children have poorer self-efficacy regarding their ability to take part in physical activity, and so withdraw from taking part in opportunities to improve their fitness (Cairney, Hay, Faught, & Hawes, 2005). This explanation has also been used to explain the fact that DCD has been found to associate with obesity (Rivilis et al., 2011). Alternatively, this link with obesity may stem from poorer early diet, including a lack of nutrients, since both motor coordination (Kitsao-Wekulo, Holding, Taylor, Kvalsvig, & Connolly, 2013) and obesity (Sothern, 2004) have been linked to a lack of nutrients. The relation between motor coordination and obesity is explored further in Chapter 3.

Beyond the physical domain, a systematic review by Zwicker, Harris, and Klassen (2013) found that DCD impacts on several quality of life domains, including social acceptance, self-perceived competence, anxiety and depression. For example, in a sample of 109 children with DCD (aged 8-14 years, <15th percentile on MABC), the children reported lower self-worth and higher anxiety than the control group (Skinner & Piek, 2001). Likewise, a sample of 265 children aged 7-15 years were split into those scoring <15th percentile on the MAND, and those scoring >15th percentile (Piek, Baynam, & Barrett, 2006). Those children classified as having DCD were found to judge themselves as poorer than their peers on measures of academic competence, athletic competence, physical appearance and behaviour. This may lead to these children participating less in social group play in the playground, and spending more time in isolation (Smyth & Anderson, 2000, 2001). Alternatively, it may be that because of their poorer motor ability in social group activities, other children exclude them from participating (Smyth & Anderson, 2000). Children with DCD have also been found to have poorer academic outcomes at school, exacerbated by the fact that skills such as handwriting constitute so much of the school day and assessments of academic attainment. These links are explored further in Chapters 4 and 6.

1.2.8 Intervention

The EACD guidelines recommend that every child with DCD should receive intervention, and that it is crucial for children to gain access to this as early as possible (Blank et al., 2012). Current intervention approaches can broadly be categorised into two types: process- and task-oriented. Firstly, process-orientated interventions purport to target the underlying functional motor control deficits (e.g. ‘balance’ and ‘visual-motor perception’). One of the most widely used process-orientated interventions is Sensory Integration Therapy (SIT) (Ayres, 1979), which involves providing sensory (including tactile or proprioceptive) stimulation. However, evidence supporting SIT as a treatment for DCD is limited (Smits-Engelsman et al., 2013; Sugden, 2007). Other process oriented approaches involve attempting to train specific areas of the brain implicated in motor control, such as the cerebellum (Sugden, 2007). In contrast, task-orientated interventions focus on identifying specific problems with a particular task, and then using strategies such as directed practice, altering the environment, and breaking up tasks into individual components in order to improve performance (Sugden, 2007). This approach may also involve teaching cognitive problem solving strategies, with the aim that the child learns how to transfer these learning strategies to different tasks. For example, Cognitive Orientation to Daily Occupational Performance programme (CO-OP) (Polatajko, Mandich, Miller, & Macnab, 2001) involves the child actively choosing their own goals and developing an executive problem-solving strategy to achieve them. The rationale behind these two approaches is discussed in Chapters 2, 5 and 6.

1.3 Summary and thesis outline

Movement problems are linked to a wide range of negative educational, social and health consequences. This fact has led health professionals to create a diagnostic label for individuals with movement problems (DCD), and encouraged researchers to produce tools for identifying these individuals. However, the diagnostic criteria for DCD is vague, and after a number of published consensus and guideline papers (Blank et al., 2012; Sugden, 2006), there is still no agreement on a single recommended measure to measure poor motor performance. This is partly due to the fact that, apart from a small number of children with severe problems in all domains, children often only express difficulties with specific activities or in certain situations (Gilger & Kaplan, 2001). The reasons for why this might be are explored in Chapter 2 of this thesis, with the World Health Organisation's International Classification of Functioning, Disability and Health (ICF) framework applied and considered as a reference point to clarify the confusion. The ICF states that disability is determined by three interacting factors: body functions; activity; participation (mediated by other contextual factors). Chapter 2 explores the relation between motor deficits at these three levels, by using the MABC as a measure of activity, the DCDQ as a measure of participation, and the Clinical Kinematic Assessment Tool (CKAT) as a measure of function. The CKAT, which is used in all the experimental chapters, is described below.

1.3.1 The Clinical Kinematic Assessment Tool

The Clinical Kinematic Assessment Tool (CKAT) was designed to offer a portable alternative to laboratory based assessments of the kinematics of human movement (Culmer, Levesley, Mon-Williams, & Williams, 2009). The CKAT test battery consisted of three tasks (tracking a moving dot, aiming between a series of dots and tracing along a path), all performed with a 'pen' stylus on a tablet computer. For each task, a large amount of kinematic data is recorded by the software (see Culmer et al. (2009) for full details of underlying software architecture). Overall score on the CKAT has been used as a measure of fine motor control at the activity level (Flatters, Hill, Williams, Barber, & Mon-Williams, 2014; Flatters, Mushtaq, Hill, Holt, et al., 2014; Hill et al., 2016), and in particular, the measure can be used as a measure of 'pen-skill' ability as it requires the application of precise forces in order to move the pen.

Importantly, the three tasks that children complete on the CKAT (tracking, aiming and tracing) tap into different sensorimotor control processes, meaning the CKAT can be used to measure motor function. The tracking task (see Figure 1.1a) involves following a moving dot with the stylus around a figure-8 type loop. This is first accomplished with no guideline of the path the dot is taking, and the dot follows this loop for three iterations at a slow speed, then a medium speed, then a fast speed. The task is then repeated with a visible guideline. Completing this task can be achieved in two ways – either through compensatory control, meaning that the child is continually aiming to reduce the error between the tip of their stylus and the centre of the moving dot (resulting in shorter, less smooth movements), or by predicting the motion of the dot and generating a smoother continuous movement.

The aiming task requires the child to draw between a series of 75 dots as quickly and as accurately as possible (see Figure 1.1b). The dots are presented in one of five possible spatial locations, and the order of the location of each dot is fixed. During the final 25 movements, six 'jump' conditions are introduced, whereby the location of the target dot 'jumps' to the next location before it has been reached by the child. This feature is designed to require online corrections of movement. Completing the standard aiming movements involves implementing fast feed-forward mechanisms and online corrections, whilst balancing the speed/accuracy trade-off, in order to reach the desired end-point location.

Finally, the tracing task requires the child to draw along an abstract path, keeping between the path boundaries (see Figure 1.1c). Two possible paths are presented (where the second path is a mirror image of the first, flipped in the horizontal plane). In addition, a black box is presented over the first segment of the path, which then moves to the next segment of path every five seconds. The child is instructed to try to keep the speed of their tracing such that they stay within the limits of the box at any given point. This was designed to try and limit the influence of the speed/accuracy trade off. Successful completion of the tracing task involves both feedforward and feedback sensorimotor processes - accurate prospective control based on information about the future direction of the path, as well as continuous online corrections to reduce the steering error.

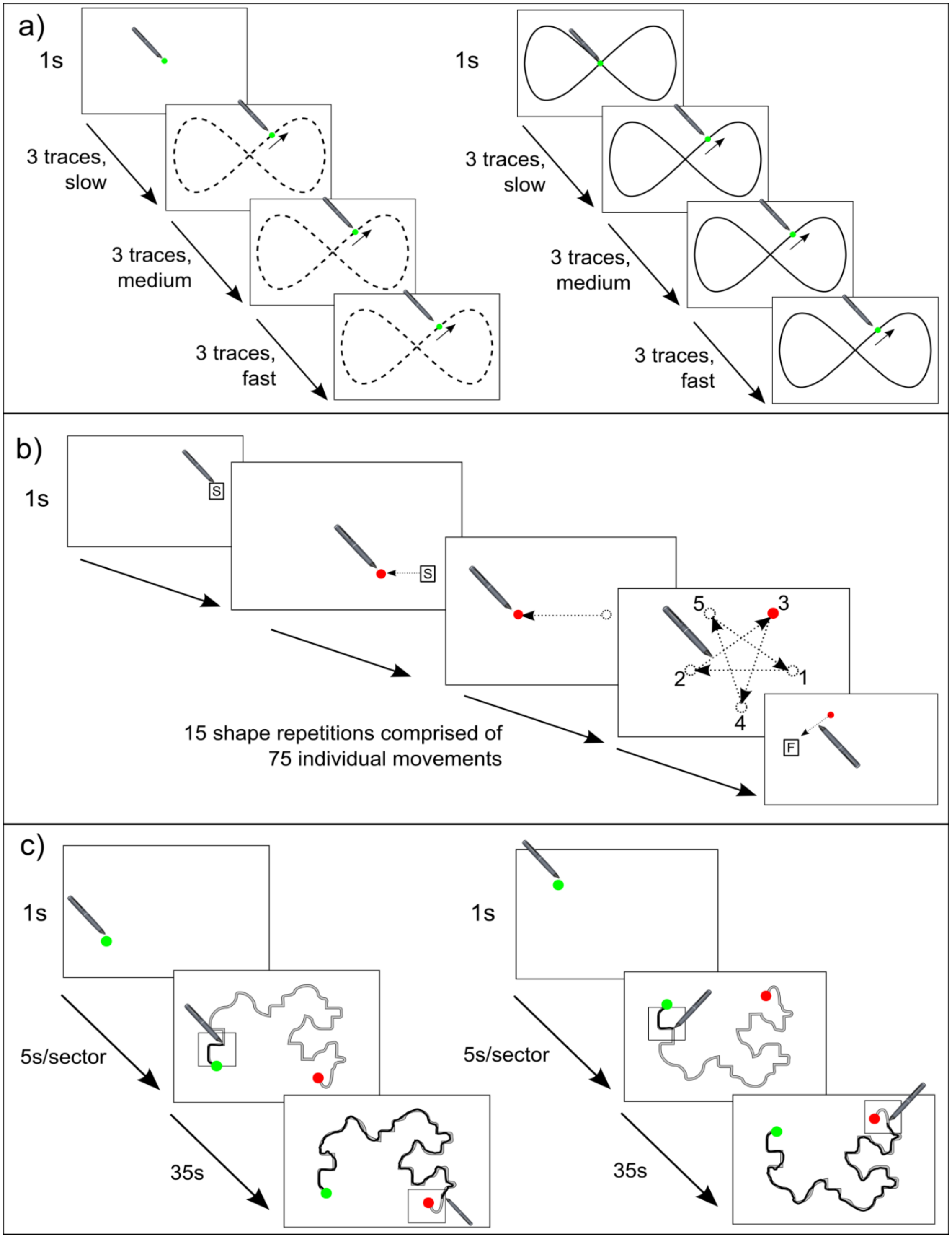

Figure 1.1 Order of presentation and timings for CKAT battery tasks

a) Demonstration of the tracking trial without the visible guideline (left), with the visible guideline (right); b) Schematic of the aiming task involving aiming between dots in pattern shown; c) Schematic of the two path shapes completed in tracing task. Figure taken from Flatters et al. (2014)

CKAT collects a large number of kinematic variables in the temporal and spatial domains. However, for the experiments presented in this thesis, only single outcome measures for each of the three tasks were used as these were previously shown to exhibit good validity and discriminatory properties (Culmer et al., 2009; Flatters, Hill, et al., 2014). For the tracking task, average root mean square error (RMSE) is calculated as the straight-line distance (in mm) between the centre of the target and the tip of the stylus at each sampled time point. RMSE is calculated for each speed of the dot (slow, medium or fast), both with and without the guide line, and the median RMSE for these six conditions was then calculated as the tracking outcome variable. For the aiming task, the average movement time (MT) for the first 50 aiming movements (out of a total of 75) is calculated as the outcome variable for the aiming task. For the purposes of this thesis, measurements from the last 25 movements involving the 'jump' trials were not examined. For the tracing task, average path accuracy (PA) and path-length time (PLT) are extracted for each of the six tracing paths. A penalised path accuracy score (pPA) is then calculated for each path in order to adjust for the time taken, based on the 'ideal' 36 seconds that was prompted by the moving box during the task. This is calculated using the formula:

$$pPA = PA \times (1 + \left| \left(\frac{PLT}{36}\right) - 1 \right|)$$

The median pPA for each of the six tracing paths is then calculated for the tracing outcome variable.

As a measure of underlying sensorimotor control, CKAT has been used successfully to show subtle differences in motor function between children aged 4-11 years, on the basis of age and sex (Flatters, Hill, et al., 2014). Involving simply an appropriate tablet computer to run it on, it is extremely practical as a tool for screening large numbers of children, as it can be easily transported to schools, and multiple testing stations can be set up at one time. It is also relatively quick to run, requiring between 15 and 20 minutes per child. In contrast, the

Movement Assessment Battery for Children (MABC) (Henderson & Sugden, 1992), the most commonly used assessment for diagnosis and screening poor motor performance in Europe (Schoemaker, Niemeijer, Reynders, & Smits-Engelsman, 2003), takes between 30-45 minutes per child. In addition, the CKAT variables are generated automatically, saving additional time over assessments such as the MABC where the assessment is scored manually.

The CKAT, as an objective, continuous measure of functional motor ability can therefore be used to examine the relation between motor ability and other outcomes in the general population. For example, a relation between DCD and obesity has been observed in children, with evidence that the relation gets stronger with age (Rivilis et al., 2011). It could be argued that poor motor skills lead to a less active child which promotes obesity, or alternatively that obesity itself impairs motor skills. However, the pattern of causation remains unclear because previous longitudinal research only examined children where the relation was already well established at baseline. In addition, the broad measures of motor-skill product used previously may not have been appropriate for examining underlying motor control (e.g. confounded by impaired muscle strength). Therefore, in Chapter 3, the CKAT is used as a measure of functional motor ability to examine the relation between sensorimotor deficits and obesity.

In addition, whilst all previous research has been based on the classification of children as having DCD, or not having DCD, in reality, movement ability is a continuous and dimensional construct (Culmer et al., 2009). Therefore, whilst there is converging evidence from population based studies suggesting a relation between sensorimotor control problems and educational attainment (Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010), it nevertheless remains unknown whether this is a general dimensional relation, or confounded by ascertainment and referral bias from the use of clinical populations. Chapter 4 addresses this by using the CKAT as a measure of sensorimotor control, and examining whether specific motor functions are related to academic attainment outcomes in mathematics, reading and writing.

Despite the severe and widespread consequences of DCD, knowledge of this disorder is poor among UK clinicians. Poor or very poor knowledge of DCD was reported by 15.7% of paediatricians, and 67.3% of psychiatrists (Kirby, Salmon, & Edwards, 2007), and the pathway to get a diagnosis is often long and frustrating for the child and their parents (Missiuna et al., 2006), involving multiple tests and often a number of different health care and education professionals (Wilson, Neil, Kamps, & Babcock, 2013). In addition, once a diagnosis has been made, there is often a long waiting list to gain access to intervention. For example, in their report on waiting lists and times for occupational therapy, Dunford & Richards (2003) found that children with DCD comprised of around 30% of all children receiving occupational therapy, but almost 62% of children who were waiting for assessment. Therefore, there is a clear requirement for alternative intervention strategies for children with motor deficits.

Chapters 5 and 6 examine two alternative methods of intervention (based on the results from the previous chapters) that have the potential to be used in schools. One intervention, using a robotic haptic device designed to target specific underlying sensorimotor difficulties, was run as a cross-over intervention in children identified as having motor difficulties. The effectiveness of this intervention is assessed in Chapter 5. The second intervention was developed to be run with minimal costs, as a school-led intervention to improve handwriting. The design of the intervention and the feasibility of this intervention strategy is reported in Chapter 6.

1.4 The research setting – Born in Bradford

All of the work presented within this thesis constitutes nested projects within a large longitudinal research study called Born in Bradford (BiB) (Wright et al., 2013). BiB was established in 2007 in response to the high rates of childhood morbidity and mortality seen in the City of Bradford. Bradford is the 6th largest city in the UK, and the 26th most deprived local authority in areas such as income, education, health and employment according the Index of Multiple Deprivation 2010 (ONS, 2011). Bradford also has a higher rate of infant mortality

(9.4 deaths/1000 births) compared to the UK average (5.5 deaths/1000 births) (APHO, 2012). The BiB project was therefore set up with the aim of examining the genetic, environmental, behavioural and social factors that influence the health and development of the children in the city. All mothers who gave birth at Bradford Royal Infirmary between 2007 and 2011 were invited to take part, which resulted in a cohort of 13776 children. The majority of the cohort is bi-ethnic, with roughly equal split between White British and Pakistani ethnicities (Wright et al., 2013).

The reach of the Born in Bradford project goes far beyond the cohort study. For example, the 'Starting School' project involved taking school readiness indicators of motor skills (using the CKAT), vocabulary, and letter identification, not only with the BiB children, but all children in Reception class (aged 4-5 years) across Bradford. A subsample of these data were used in Chapter 3. The schools were provided with the results of these measures so that they could identify those children that might need extra help. In the screening studies described in Chapters 2 and 4, the information collected on the children regarding their motor abilities was directly fed back to the schools. The interventions described in Chapters 5 and 6, took part within 11 schools in some of the most deprived areas of Bradford. An integral part of the experiments described in this thesis has involved building on the links between the BiB project and the schools in Bradford.

CHAPTER 2

FUNCTION, ACTIVITY AND PARTICIPATION IN CHILDREN IDENTIFIED WITH MOVEMENT PROBLEMS

2.1 Introduction

Movement problems are associated with negative consequences in a large number of domains. Physically, children with movement problems have been shown to be heavier and less physically active than their peers (D'Hondt, Deforche, De Bourdeaudhuij, & Lenoir, 2009; Joshi et al., 2015; Rivilis et al., 2011), and because of this are at a higher risk of cardiovascular disease and type two diabetes (Faught, Hay, Cairney, & Flouris, 2005; Joshi et al., 2015; Schott et al., 2007). In addition, children with movement problems have a higher risk of mental health problems (Hill et al., 2016). There have also been suggestions of links between poor motor abilities and lower academic outcomes (Grissmer et al., 2010; Roebers et al., 2014).

The very real problems faced by children and adults with movement difficulties have resulted in a series of attempts to provide support mechanisms for these individuals. One outcome of these attempts is the diagnostic construct of developmental coordination disorder (American Psychiatric Association, 2000; Sugden, 2006) and a number of tests that aim to identify individuals with 'poor motor performance' (Zwicker, Missiuna, Harris, & Boyd, 2012). Nevertheless, there is general consensus that these efforts have not been successful and the majority of children with movement problems are not getting the support they require (Camden, Wilson, Kirby, Sugden, & Missiuna, 2015; Dunford, Missiuna, Street, & Sibert, 2005; Missiuna et al., 2008).

One major reason for the lack of progress appears to be related to the imprecise nature of 'movement problems' as a category, both because of the breadth and the depth of the concepts this construct encapsulates. At its core, sensorimotor control is defined as the use of sensory information to generate motor commands and thus perform an action (Wolpert & Kawato, 1998). This means that every interaction that humans have with the world could be defined as a sensorimotor activity: from eye movements, to walking along a path to gripping a pen and moving the hand in order to write. However, very few activities involve purely motor requirements – many also involve 'high-order' cognitive skills such as attention, memory and language. Handwriting is a particularly notable example, involving not only a visuo-motor element but many cognitive and language components (Medwell, Strand, & Wray, 2009; Volman, van Schendel, & Jongmans, 2006). What is meant by a 'movement problem' therefore, requires careful consideration, clarification and classification.

The framework described in the World Health Organisation's (WHO) international classification of functioning, disability and health (ICF) outlines how impairments (such as deficits in sensorimotor control) relate to disability. The ICF identifies three levels: the body function and structure level (including physiological and psychological body functions); the activity level (the execution of a task) and the participation level (the involvement in a real life situation) (World Health Organisation, 2001). So, in the case of 'motor problems', there could be a deficit at the functional level (for example, problems with the sensorimotor control processes involved in using visual information to predict the time-to-arrival of a ball), at an activity level (for example, kicking an approaching ball), or at a participation level (for example, playing football with friends). However, the ICF framework suggests that it is not the case that a functional deficit will automatically result in an activity deficit, which will automatically result in a participation restriction. Rather, these different levels are proposed to interact with each other in a complex manner (see Figure 2.1). For example, a child might have functional difficulties in grasping and manipulating a pen but have excellent cognitive capabilities (e.g. language skills, creative writing ability and the ability to think quickly) which might mask the motor deficits at the activity and participation level.

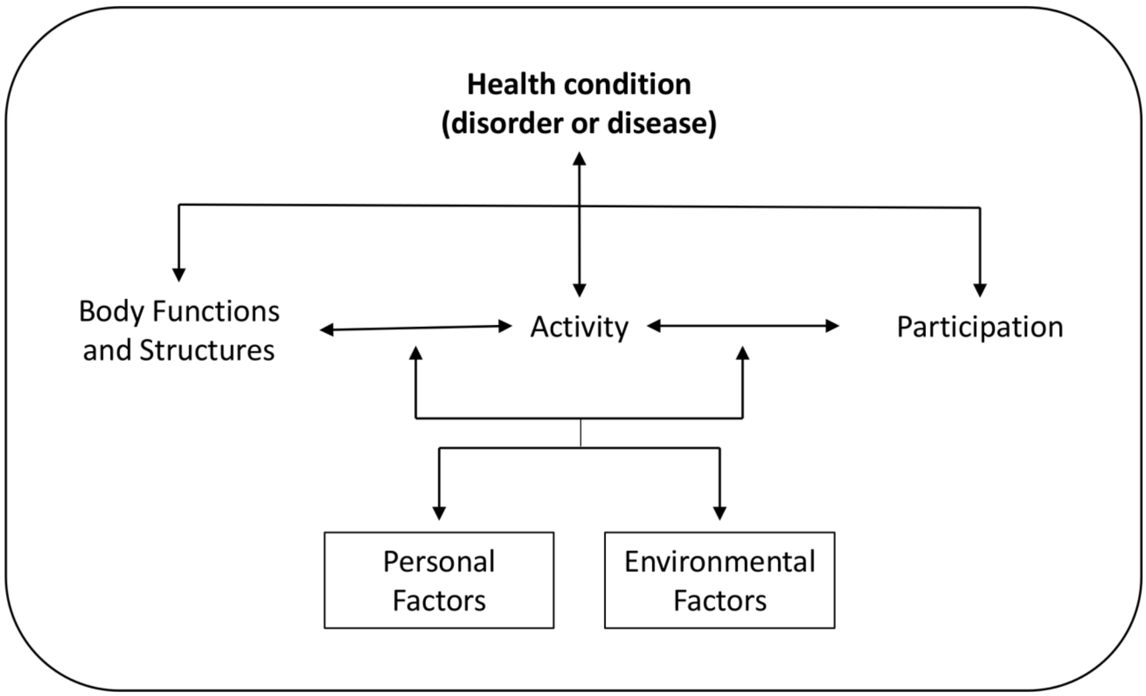

Figure 2.1 Framework of International Classification of Functioning, Disability and Health (World Health Organisation, 2001)

The extent to which the function, activity and participation deficits overlap is in part mediated by contextual factors - both personal and environment. Personal factors include aspects such as gender, age, social background and past experiences, whereas environmental factors include individual factors such as home and school physical environments, and also societal factors including formal and informal social structures. These components represent barriers and facilitators to the potential relations between different levels of deficit. For example, an activity deficit may not limit participation if the environment can be altered to accommodate this - a child may not be able to write with a standard pen, but if a modified pen (or keyboard) was provided then this could allow the child to participate in a writing exercise.

The complex relation causing some children with a functional motor difficulty to show difficulties at the activity level whereas others do not appear to have difficulties, can also be explained by models such as Pennington's multiple deficit model (see Figure 2.2) (Pennington, 2006). This model proposes that firstly, there are multiple risk and protective genetic and environmental factors that interact with each other to increase or decrease liability to a disorder. These may then alter multiple neural systems, which in themselves overlap. Altered cognitive processes may result due to these altered developmental neural pathways, processes which also interact and overlap. Therefore, dysfunction in one cognitive process, or one neural system, or one genetic factor is not necessarily sufficient in itself to produce a particular disorder.

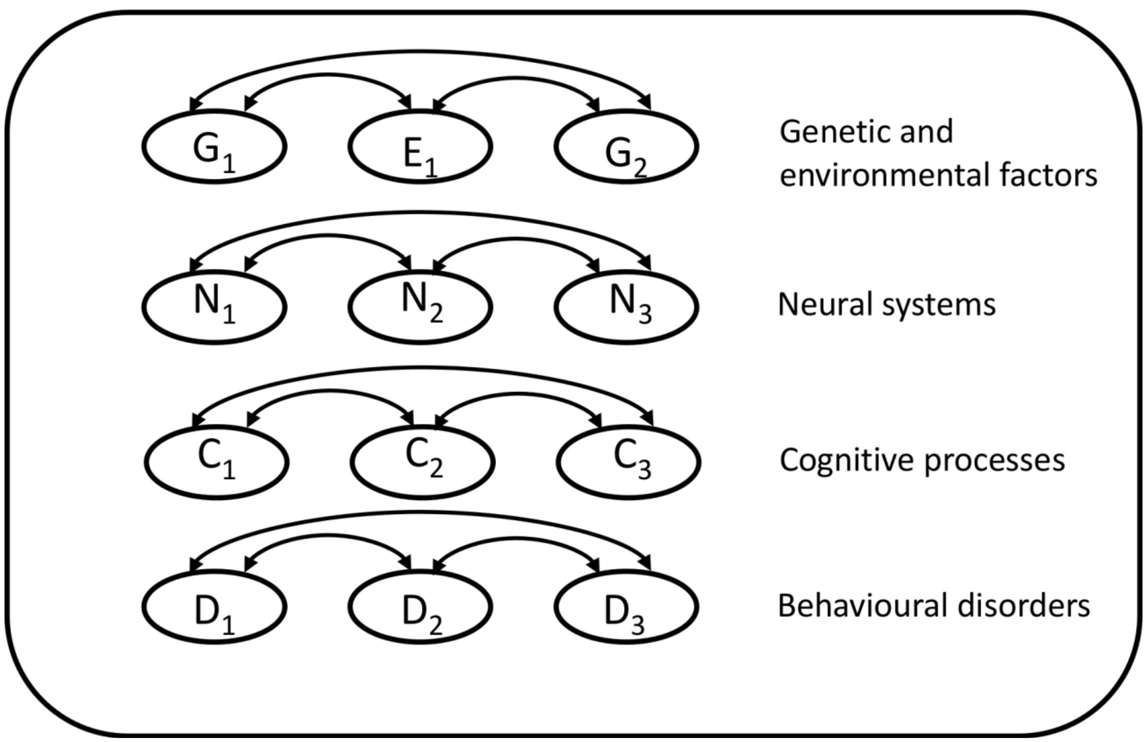

Figure 2.2 Pennington's multiple deficit model. Reproduced from Pennington (2006). Arrows indicate interactions between different factors at each level.

The Pennington model also offers a framework to explain why there are such high occurrences of co-morbidity in developmental disorders. For example, up to half of all children with specific language impairment also show 'motor problems' (Archibald & Alloway, 2008), and almost half of children with 'motor problems' meet the criteria for attention deficit hyperactivity disorder (ADHD) (Dewey, Kaplan, Crawford, & Wilson, 2002). Each 'disorder' results from a specific profile of cognitive and etiologic risk factors, but these overlap between different disorders (Pennington, 2006; van Bergen, van der Leij, & de Jong, 2014).

Van Bergen, van der Leij, and de Jong (2014) also suggest two further aspects to this complex relation within their multi-generational multiple deficit model – a parental and extra-parental environment. The multi-generational multiple deficit model highlights that parents pass their genetics to their children, but also influence their children's outcomes through their own phenotype (for example, their own cognitive abilities), and the environment they provide for their child. The extra-parental environment includes aspects such as teachers at school and peer interactions. Although when the child is young these are largely influenced by parental choices, as children get older and become more independent, they exert more control over their environment. Both of these factors interact with each other, and the neural and cognitive development of the child to ultimately result in the presence or absence of deficits (such as 'motor problems'). If these 'complex' models are correct, measuring a deficit at either the functional, activity or participation level will only give limited information about whether the child will show a deficit at another level. This has implications for the identification of children with 'motor problems', their clinical diagnosis, and how best to treat them.

2.1.1 The identification of children with motor problems

According to the ICF model, there are three levels at which motor problems could be measured: function, activity, and participation. Measuring motor function in the case of physical disability is relatively straight forward. For example, measuring the spasticity of a limb present in Cerebral Palsy. In the case of movement deficits, it is less straight forward. In cases such as this, function can be measured is possible with precise motion tracking systems that record kinematic information. Examples of this include eye movement tracking systems (Meyer & Constantinidis, 2005), and motion tracking opto-electric systems (Anglin & Wyss, 2000). These systems allow the motor responses to carefully controlled input to be assessed. However, in the case of identifying children with functional motor problems in the general population, many such systems, which require controlled laboratory conditions, are impractical. One system that does have the potential to be used as a screening tool for functional motor difficulties is the Clinical Kinematic Assessment Tool (CKAT) (Culmer et al., 2009). Whilst this requires sensorimotor function to be extrapolated on the basis of an activity (for example, tracking a moving target), the CKAT tasks are simple enough that the sensorimotor requirements of each task can be identified, and the software allows precise kinematic information to be recorded (see Section 1.3.1). This therefore allows a different level of measurement from an assessment at the activity level where only the output of the movement is assessed, such as the Movement Assessment Battery for Children (MABC) (Henderson & Sugden, 1992). Crucially, it also allows insight into which sensorimotor functions may be impaired. For example, poor performance on the CKAT tracking task could suggest difficulties with compensatory control.

There are more difficulties with measurement at the level of activity. There are many standardised assessment tools which all aim to identify motor problems at the activity level, without any one tool being recommended as the 'gold-standard' (Blank et al., 2012). For example, the MABC (Henderson & Sugden, 1992), is the most commonly used test in Europe for the diagnosis of DCD (Geuze et al., 2001) and involves assessing the child's performance on a number of specific motor tasks. For example, an overall 'balance' score is derived from performance on two tasks – one involving balancing whilst moving, the other balancing whilst stationary. In comparison, the Bruininks–Oseretsky Test of Motor Proficiency (BOTMP)

(Bruininks, 1978) assesses performance on a different range of activities including strength and agility. The main issue is that there is often very little agreement found between performance on different activity measures. For example, Chen, Tseng, Hu, and Cermak (2009) screened 170 children on both the MABC and the BOTMP, and found low agreement ($\kappa = 0.43$) in terms of which children were identified as having difficulties. Studies such as Chen et al's (2009) led a review by Venetsanou et al. (2011) to conclude that the MABC should not be used as the sole measure to identify children with motor problems. Furthermore, within the tests themselves, performance on one task has often been found to only have a small relation with performance on another task. For example, Haga, Pedersen, and Sigmundsson (2008) found that, in a group of 91 children aged 4-5 years, correlations between individual test items on the MABC only ranged from .19 to .31. This highlights the fact that these tests will be limited by the necessarily arbitrary choice of what activities are chosen to be measured. However, common between these tests are a focus on the end-result of the movement, and scoring on a limited, categorical scale (for example, pass/fail).

There are also difficulties measuring participation. Although either the child, their parent, or their teachers can be asked about their levels of participation, this clearly involves a large amount of subjectivity. A number of questionnaires have been developed that aim to quantify participation. For example, the Developmental Coordination Disorder Questionnaire (DCDQ) is a fifteen item questionnaire that is designed to be filled out by parents, although teachers and other carers can also complete it (Wilson & Crawford, 2007; Wilson et al., 1998). This questionnaire focuses on the skills that may be impaired in daily life, such as tying shoelaces, and children are rated on Likert scales of 1-5 compared to other children their own age. However, many of the questions involve asking about specific activities, rather than participation per se. This confusion as to what level the DCDQ measures ‘motor problems’ in can be seen in the literature, with some studies using it as a measure of activity (Crawford, Wilson, & Dewey, 2001; Venetsanou et al., 2010), and others describing it as a measure of motor function (Tal-Saban et al., 2012; Wang, Tseng, Wilson, & Hu, 2009).

However, it has been argued that the grounding of the questions in real-life situations makes this a useful means of assessing participation (Smits-Engelsman et al., 2015). In any case, measuring at the level of participation does not look at how well the movement or activity can be performed, but instead whether the child chooses to perform the activity in every-day situations (rather than test conditions).

Although there is clearly some overlap in how well these three measures (CKAT, MABC and DCDQ) fit into the three ICF categories (function, activity and participation), they clearly do measure at different levels from each other (kinematics, outcome performance, and every-day performance). Therefore, for the purposes of the following study, CKAT will be used as a measure of function, the MABC will be used as a measure of activity, and the DCDQ will be used as the measure of participation.

2.1.2 Diagnosis of clinical problems

Considering the children who end up being recognised as having coordination difficulties, such difficulties are typically first identified as impairments in participation. This is normally flagged via one of two (not mutually exclusive) 'diagnostic' pathways: the Medical (i.e. the child referred to occupational therapy) and the Educational (i.e. the child identified as having handwriting difficulties).

According to the DSM-5 diagnostic criteria for Developmental Coordination Disorder (American Psychiatric Association, 2013), the clinical label of Developmental Coordination Disorder (DCD) may be given in cases where: “(A) The acquisition and execution of coordinated motor skills is substantially below that expected given the individual’s chronological age and opportunity 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 vocational activities, leisure, and play. (C) Onset of symptoms is in the early developmental period. (D) The motor skills deficits are not better explained by intellectual disability (intellectual developmental disorder) or visual impairment and are not attributable to a neurological condition affecting movement (e.g., cerebral palsy, muscular dystrophy, degenerative disorder)."

However, if the ICF model is applied, substantial issues begin to arise with the DSM framework for clinical diagnosis. Firstly, Criterion A arguably refers to a deficit at a functional level but, since the underlying difficulties are then described as being manifest in different skills at the level activity "(e.g. catching, throwing, kicking…)", this suggests that the child would have to show a deficit at both the functional and the activity level for a diagnosis to be made. Furthermore, Criterion B also requires that the functional deficit interferes with an activity level deficit "activities of daily living". However, it also requires there to be a participation deficit in "academic/school productivity, prevocational and vocational activities, leisure and play". Finally, Criterion D requires that the poor motor performance not be attributable to a neurological condition. However, deficits of sensorimotor control are, by definition, deficits in neurological systems. In short, the DSM-5 criteria appear to suggest that impairment must be seen across multiple levels of the ICF framework for a diagnosis of DCD. However, if impairment across these levels is not linear, as suggested by the ICF (World Health Organisation, 2001) and the multiple deficits model (Pennington, 2006), then this raises questions about how to classify children who might have a functional motor problem, but do not have difficulties at the activity level, or conversely, children who seem to struggle with certain motor skill activities, but show no underlying sensorimotor deficit.

Furthermore, it has been recommended that standardised tests such as the MABC are used (Blank et al., 2012; Cacola, 2014) in order to satisfy criterion A, and yet this measures at the activity and not the functional level (Blank et al., 2012). If the ICF guidelines are a useful framework, then a test at the activity level will not be particularly informative about the results at the functional level, which would suggest that using such a test would not, in fact, satisfy criterion A in the DSM-5 guidelines. This suggests there is an urgent need to determine the relation between function, activity and participation within the broad construct of 'poor motor performance'.

2.1.3 Treatment of motor problems

Traditionally one of two distinct therapeutic approaches has been adopted following identification of children with 'motor problems', either process- or task- oriented. Process oriented interventions target underlying functional deficits such as balance, or sensorimotor integration. The concept behind these types of intervention is that treatment of the underlying functional deficit will translate to improvements in activity which will, in turn, result in improvements in participation. However, this rationale if only justified if there is a linear, rather than complex, relation between the levels of description underpinning the construct of 'poor motor performance'.

Task-oriented interventions on the other hand, involve identifying particular problems encountered during specific tasks, and then targeting this specific skill. This intervention works on the basis that although, for example, functional deficits are influencing activity, the link between them is not direct enough to merit treating the underlying deficit, if the goal is to improve performance at an activity level.

Traditionally, different fields (i.e. education and medical) have favoured different approaches. Occupational therapists in clinical settings have tended to favour process-oriented approaches, on the basis that activities cannot be taught in the time they have with each child (Smits-Engelsman et al., 2013; Sugden, 2007). Conversely, in educational settings, specific skills such as handwriting are particularly relevant for academic success, and therefore there tends to be a focus on favouring a task-oriented approach (i.e. a focus on teaching specific writing skills). In a number of reviews and meta-analyses of current intervention practices, task-oriented approaches have tended to be more effective than process-oriented interventions (Pless & Carlsson, 2000; Smits-Engelsman et al., 2013; Sugden, 2007), which supports the ICF framework regarding the complex relation between different levels of disability.

However, the confusion regarding the measures that are used to assess the effectiveness of such interventions, and what levels they are measuring at, means this is by no means definitive. It is therefore, necessary to empirically examine the relation between function, activity and participation in order to be able to evaluate the usefulness of the ICF framework. Evidence of a strong causal framework when modelling the relation between measures of function, activity, and participation would encourage the use of process-orientated intervention strategies. Contrastingly, a weaker causal relation would support more task-orientated approaches, as this would suggest a positive 'cascade' effect from function would be theoretically unlikely.

2.1.4 Measuring the relation between function, activity, and participation

In this study, the structural relation between deficits in function, activity and participation were explored in two groups of children (one medically and one educationally referred for having 'participatory' motor coordination problems) to investigate the extent to which the ICF model relates to children identified with movement problems. Performance in these children was assessed at the functional level using the CKAT, at the activity level using the MABC, and at the participation level using the DCDQ together with teacher judgements.

2.2 Method

2.2.1 Participants

2.2.1.1 School-based sample

All 460 children attending a local primary school in the city of Bradford (West Yorkshire, UK) were invited to take part in the study. Informed parental consent and individual assent was obtained for 415 of these pupils (90% of the school roll; aged 4-11 years old; 220 males and 195 females). The school was comparable to the national averages in terms of academic attainment, attendance and proportion of pupils receiving free school meals (a proxy indicator of social deprivation). The majority of pupils were either of White British or Pakistani heritage, with roughly even proportions of each. The individuals participated in the study between December 2012 and July 2013. Ethical approval was granted from the University of Leeds Ethics and Research committee (ref: 13-0112). Table 2.1 reports descriptive statistics for the sample's age, sex and handedness, across categorical age-bands.

Table 2.1 Descriptive statistics for sex, handedness and age across age-bands for school-based and clinical samples

Sample		Total	4-4.99	5-5.99	6-6.99	7-7.99	8-8.99	9-9.99	10-10.99	11-11.99
School-based sample	n	415	35	69	57	62	60	55	64	13
	Mean age	7.72	4.61	5.47	6.45	7.44	8.46	9.39	10.42	11.10
	Gender Male:Female	220:195	22:13	37:32	35:22	25:37	34:26	30:25	30:34	7:6
	Handedness Right:Left	377:38	32:3	64:5	51:6	54:8	54:6	53:2	57:7	11:2
Clinical sample	n	33	0	3	5	8	4	0	5	8
	Mean age	8.72	n/a	5.47	6.20	7.46	8.73	n/a	10.80	11.49
	Gender Male:Female	26:7	n/a	2:1	5:0	7:1	2:2	n/a	4:1	5:3
	Handedness Right:Left	24:9	n/a	3:0	4:1	5:3	3:1	n/a	3:2	6:2

2.2.1.2 Clinical sample

The clinical sample were consecutive referrals of children who were referred for assessment of their motor skills to the Occupational Therapy department of the Royal Aberdeen Children's Hospital. Informed consent was gained from 33 parents and children (see Table 2.1 for descriptive statistics). Ethical approval for this sample was gained from the University of Aberdeen.

2.2.2 Materials

Three measures were used within the study, assessing function deficit, activity deficit and participation deficit:

2.2.2.1 Function - Clinical Kinematic Assessment Tool (CKAT)

The Clinical Kinematic Assessment Tool (CKAT) is a computerised test of motor skill, measuring kinematic performance on three tasks at the activity level, and also able to predict movement function with comparable accuracy to that of high-tech laboratory based systems (Culmer et al., 2009). It has discriminatory ability on the basis of age and gender (Flatters, Hill, et al., 2014), and requires a number of movement skills such as inverse control and tracking movement.

The CKAT is a battery of computerised tests measuring pen-skills and manual visuo-motor coordination (Culmer et al., 2009). The battery is run using Kinelab software on Toshiba tablet computers (Portege M700-13P, screen size: 303 x 190 mm, 1280 x 800 pixels, 32 bit colour, 60 Hz refresh rate), with a pen-shaped stylus (140 x 9 mm diameter) used as an input device (see Culmer et al. (2009) for details of the underlying software architecture). For each of the three tasks, interactive visual stimuli are presented on the computer's screen and objective kinematic responses using the handheld stylus are recorded. The three tasks in the battery are: (a) tracking a moving dot around a figure-8 loop at different speeds (with and without a guide), (b) make a series of aiming movements between dots, and (c) trace along a series of abstract paths. These specific tasks are novel (minimising potential cultural bias) and are designed to assess specific control mechanisms that are considered to underpin performance on many everyday tasks that require manual skill. For example, tracing requires precise force and inverse control.

2.2.2.2 Activity - Movement Assessment Battery for Children Second Edition (MABC-2)

The MABC-2 is designed for use with children aged 3–16 years (Henderson, Sugden, & Barnett, 2007). A total of 8 tasks are completed, covering manual dexterity, ball skills and static and dynamic balance, with slightly different tasks for the different age bands (3-6 years, 7-10 years and 11-16 years). For example, in the 3-6 years age band, the manual dexterity tasks are posting coins in a box, threading beads on a string, and a path tracing task using a pen. Standardised scores for each of the sub-sections as well as a total battery score can be calculated from raw scores. In the MABC manual, Henderson, Sugden, & Barnett (2007) suggest that total scores falling below the fifth percentile in any category should be considered as indicative of a definite motor problem, while scores between the fifth and 15th percentile suggest a degree of difficulty that is borderline, but needs further monitoring.

2.2.2.3 Participation - Development Coordination Disorder Questionnaire (DCDQ)

The revised version of DCDQ (the DCDQ'07) is recommended for use with children aged 5-15 (Wilson et al., 2009).This questionnaire was designed to be completed by parents, although it can be used by teachers and other carers as well (Wilson et al., 2009). The questionnaire is comprised of fifteen statements divided into three subscales: 'Control during movement' (6 questions); 'Fine Motor/Handwriting' (4 questions) and 'General Coordination' (5 questions). For each statement (for example, 'Your child cuts out pictures and shapes accurately and easily'), respondents are asked to rate its accuracy as a description of the coordination skills of the child being evaluated compared to other children the same age, on a 5-point Likert scale from 1 = 'not at all like your child' to 5 = 'extremely like your child'. There are four questions relating to fine motor deficits, asking about speed of writing/drawing, legibility of writing/drawing, holding a pen with appropriate pressure, and cutting out shapes.

2.2.3 Procedure

2.2.3.1 School-based sample

For the CKAT assessment, participants were taken from class in groups of around 5, and sat with a researcher individually in a quiet area. Participants were sat at a table of appropriate height for their age with a tablet computer placed in front of them, in landscape orientation and with the screen folded flat. Participants were instructed to hold the stylus in their dominant hand and keep their non-dominant hand stationary, flat on the table top. The battery (made up of the tracking, aiming and tracing tasks) was completed in a single session lasting approximately 12-15 minutes. Following this, teachers were asked to fill out a DCDQ for all the children in their class, as well as making a binary assessment of whether they believed each child had handwriting/fine motor skill difficulties or not.

Finally, the 101 children were identified by their class teachers as having handwriting difficulties were then tested on the MABC-2. This involved a single testing session lasting around 45 minutes on a one-to-one basis with a researcher, in a small school hall.

2.2.3.2 Clinical Sample

The CKAT and MABC-2 were administered by a research assistant at a single appointment and the research assistant also asked the parent to complete the DCDQ. MABC-2 assessments were video recorded and the quality of the test administration was checked by an experienced Occupational Therapist.

2.2.4 Outcome measures

For the CKAT, different outcome measures were calculated for each task. These specific measures were chosen for their ability to discriminate between age groups, as found by Flatters, Hill, Williams, Barber, and Mon-Williams (2014). For the tracking task, root mean square error (RMSE) was calculated as the straight-line distance (in mm) between the centre of the target and the tip of the stylus at each sampled time point. The median RMSE for all conditions (fast, medium and slow for tracking 1 (without guide) and tracking 2 (with guide)) was then calculated. For the aiming task, movement time (MT) was calculated by taking the median MT for each of the 50 baseline aiming movements. For the tracing task, in order to further take into account the variation in movement time between participants, a penalised path accuracy (pPA) score was calculated, by inflating path accuracy (the mean distance away from an idealised reference path in mm) by the percentage deviation from the optimal movement time of thirty-six seconds. The median of pPA score for the six trials was then calculated. Reciprocals of these three scores were used in order to normalise the data for parametric analysis (Flatters, Hill, et al., 2014), and standardised to z-scores by year of age based on two previous screening studies (Flatters et al., 2014; Hill et al., 2016), so that comparisons could be made with the standardised scores of the other assessment tools.

As the outcome for activity, standardised scores on the MABC were used for the total test battery, and each subsection: manual dexterity (MD), aiming and catching (AC) and balance (BAL).

For the DCDQ, total score, and scores on the subsections 'control during movement' (questions 1-6), 'fine motor/handwriting' (comprised of questions 7-10), and 'general control' (questions 11-15), were taken as outcome measures. The DCDQ has only been standardised for completion by parents, and here the questionnaire was completed by the teachers.

2.3 Results

After reciprocal transformation of the CKAT scores, all the standardised variables had acceptable levels of skewness and kurtosis (see Table 2.2). Within the whole school sample, due to missing data points or absence on day of testing, complete data on all the assessment measures were obtained for 296 participants. Of the 101 children in the subsample put forward by their teacher for potential handwriting difficulties, all the children completed the manual dexterity tests of the MABC, with 100 children completing the full MABC. Complete data on all measures (MABC, DCDQ, CKAT) were obtained for 66 of these children. Out of the 33 children in the clinical sample, complete MABC and DCDQ data were obtained for all the participants. Thirty two children had valid CKAT data.

Table 2.2 Descriptive statistics for all variables (CKAT, MABC, DCDQ) in school based and clinical samples. CKAT scores reciprocally transformed

Sample	Measure	Outcome	n	Mean	(95% CI)	SD	Skewness	Kurtosis
School	CKAT	Tracking	405	0.06	(-0.03, 0.15)	0.88	-0.05	0.52
		Aiming	379	-0.35	(-0.43, -0.26)	0.88	-0.01	0.24
		Tracing	395	0.09	(0.02, 0.16)	0.72	0.03	0.20
		Total	378	-0.06	(-0.12, 0.01)	0.65	0.21	0.19
	MABC	MD	101	6.30	(5.81, 6.30)	2.48	0.12	-0.13
		AC	100	9.21	(8.58, 9.85)	3.20	-0.07	-0.20
		BAL	100	6.20	(5.57, 6.83)	3.17	0.41	-0.49
		Total	100	6.15	(5.59, 6.71)	2.83	0.68	0.40
	DCDQ	Fine Motor	348	15.68	(15.25, 16.11)	4.10	-0.93	0.13
		Control	348	25.13	(24.61, 25.65)	4.94	-1.35	1.74
		General	348	20.74	(20.28, 21.20)	4.37	-1.11	0.88
		Total	348	61.51	(60.23, 62.79)	12.16	-1.21	1.27
Clinical	CKAT	Tracking	32	-0.66	(-0.97, -0.35)	0.85	-0.06	-0.42
		Aiming	32	-0.62	(-0.92, -0.32)	0.83	-0.46	-0.61
		Tracing	32	-0.94	(-1.14, -0.75)	0.53	-0.44	0.59
		Total	32	-0.74	(-0.95, -0.52)	0.60	-0.50	-0.79
	MABC	MD	33	6.79	(5.49, 8.09)	3.66	0.67	0.17
		AC	33	7.55	(6.50, 8.59)	2.94	0.20	-0.99
		BAL	33	7.12	(6.17, 8.07)	2.68	-0.14	0.85
		Total	33	6.27	(5.25, 7.29)	2.88	0.10	-0.55
	DCDQ	Fine Motor	33	8.64	(7.44, 9.83)	3.36	0.37	-0.69
		Control	33	14.79	(12.90, 16.67)	5.31	0.31	-0.85
		General	33	10.15	(8.97, 11.39)	3.49	0.70	-0.05
		Total	33	33.58	(30.31, 36.84)	9.20	0.04	-0.74

MD = Manual Dexterity; AC = Aiming and Catching; BAL = Balance; Control = Control During Movement; General = General Coordination

Since it could be assumed that the children in the medical referral group would have more severe difficulties to the children referred educationally, it was first examined whether overall, the children in the school-based sample that had been flagged as having participation difficulties by their teachers would show differences in the standardised measures of function, activity and participation (compared to the clinically referred sample). An independent samples t-test was run with sample group (school-based or clinical) as the independent variable, and CKAT total score, MABC total standardised score and DCDQ total score as the dependent variables in turn (see Table 2.3).

Table 2.3 Summary of independent t-tests examining differences between the group identified as having difficulties in school, and clinical sample

Dependent variable	Sample	Mean	SD	d.f.	t	*p*
CKAT				117	2.08	.04*
	School	-0.47	0.65			
	Clinical	-0.74	0.60			
MABC				131	-.22	.83
	School	6.15	2.83			
	Clinical	6.27	2.88			
DCDQ[1]				91.13	7.29	.00**
	School	53.30	14.39			
	Clinical	33.58	9.20			

[1]Greenhouse-Geisser correction used

*** $p < .05$, ** $p < .001$**

Children in the school sample identified as having difficulties scored significantly better on the functional measure and the participation measure than children in the clinically diagnosed group. However, on the activity level measure, the MABC, there was no difference between the two samples.

Since there were differences between these two groups, the subsequent analysis was conducted separately for the school-based and clinical samples. First, it was examined how well scores on the functional measure of motor skills predicted performance on the activity level and then the participation level measures. Finally, it was examined how well scores on the activity level measure predicted performance on the participation measure.

2.3.1 The relation between function and activity

Standardised scores on the tracking, aiming and tracing tasks of the CKAT were entered together as predictors in a regression model with total standardised score on the MABC as the outcome in the school-based sample (see Table 2.4). Overall, the regression model predicted 17% of the variance in MABC total scores, although individually, none of the CKAT variables significantly added to this model.

Since CKAT is also a measure of ability to use a pen, it is logical that it might predict scores on the manual dexterity section of the MABC to a greater extent than the balance or aiming and catching sections. Therefore, the CKAT scores were used as predictors in three regressions, with manual dexterity, balance, and aiming and catching as the outcomes (see Table 2.4). It should be noted that the CKAT 'aiming' task and the MABC 'aiming' tasks, despite the identical label, had very different task requirements. The biggest of these being that the CKAT task involves only 'fine motor' movements (those requiring small groups of muscles (Malina, Bouchard, & Bar-Or, 2004)) whereas the MABC aiming task involves 'gross motor' movements involving large muscle groups (Utley & Astill, 2008).

Table 2.4 Regression analysis of CKAT scores on MABC total and MABC subsections in school-based sample

Outcome	Predictors	R^2	F	B	Std. Error B	β	t
Total MABC		.17	5.68**				
	Tracking			0.39	0.46	.11	0.86
	Aiming			0.78	0.41	.24	1.90
	Tracing			0.63	0.46	.15	1.37
Manual Dexterity		.16	5.92**				
	Tracking			0.04	0.37	.01	0.09
	Aiming			0.51	0.33	.20	1.53
	Tracing			0.88	0.37	.27	2.38**
Aiming and Catching		.09	2.78*				
	Tracking			0.74	0.52	.19	1.44
	Aiming			0.41	0.46	.12	0.89
	Tracing			0.19	0.51	.04	0.38
Balance		.13	4.04*				
	Tracking			0.35	0.52	.09	0.68
	Aiming			1.04	0.46	.30	2.26*
	Tracing			0.12	0.51	.00	0.02

* $p < .05$, ** $p < .001$

For each of the subsections, the functional CKAT scores explained significant amounts of variance. As predicted, most variance was explained for the manual dexterity task (16%). This was followed by the balance score (13%) and then the aiming and catching score (9%). For each of the subsections, the different CKAT tasks contributed in different ways. The tracing task was the only significant predictor in the manual dexterity scores, and the aiming task was the only significant predictor in the balance scores. None of the CKAT tasks individually contributed significantly to the model for aiming and catching.

It was then examined whether these results were replicated in the clinical sample. Standardised scores on the tracking, aiming and tracing tasks of the CKAT were entered together as predictors in a regression model with total standardised score on the MABC as the outcome in the clinical sample (see Table 2.5). Overall, the regression model was significant, explaining 32% of the variance in MABC total scores, and individually, the tracking variable was the only CKAT task that significantly added to this model.

Again, it was then examined whether there was a stronger relation between the CKAT variables and the MABC subsections. Therefore, CKAT scores were used as predictors in three regressions, with manual dexterity, balance, and aiming and catching as the outcomes (see Table 2.5).

Table 2.5 Regression analysis of CKAT scores on MABC total and MABC subsections in clinical sample

Outcome	Predictors	R^2	F	B	Std. Error B	*β*	*t*
MABC Total		.32	4.35*				
	Tracking			1.45	0.59	.45	2.45*
	Aiming			0.21	0.73	.06	0.28
	Tracing			0.87	1.02	.17	0.85
Manual Dexterity		.14	1.52				
	Tracking			1.61	0.88	0.37	1.83
	Aiming			-0.49	1.08	-0.11	-0.45
	Tracing			0.94	1.51	0.14	0.62
Aiming and Catching		.24	2.86				
	Tracking			0.43	0.67	.12	0.64
	Aiming			0.56	0.82	.16	0.67
	Tracing			1.69	1.15	.31	1.47
Balance		.34	4.86**				
	Tracking			1.52	0.52	.52	2.81**
	Aiming			0.23	0.64	.08	0.35
	Tracing			0.22	0.90	.05	0.25

* $p < .05$, ** $p < .001$

Unlike in the school-based sample, in the clinical sample only the model for balance scores was significant, sharing 34% of the variance with CKAT. Tracking was the only sensorimotor task that significantly added to this model.

2.3.2 The relation between function and participation

It was then examined whether scores on the functional task would predict scores on the measure of participation – the DCDQ. The three CKAT tasks were entered into a regression model with total DCDQ score as the outcome (see Table 2.6). The model was significant and explained 8% of the variance in total DCDQ scores. Tracing was the only significant predictor.

Again, since it may have been the case that the CKAT was a better predictor of the fine motor subsection of the DCDQ, scores for each section were entered into a regression model as the outcomes.

Table 2.6 Regression analysis of CKAT scores on DCDQ total and DCDQ subsections in school-based sample

Outcome	Predictors	R^2	F	B	Std. Error B	*β*	*t*
DCDQ Total		.08	8.48**				
	Tracking			0.76	0.84	.06	0.91
	Aiming			0.59	0.85	.05	0.69
	Tracing			3.51	0.74	.22	3.74**
Fine Motor		.06	7.09**				
	Tracking			0.03	0.29	.01	0.11
	Aiming			0.30	0.29	.07	1.02
	Tracing			1.18	0.33	.22	3.61**
Control During Movement		.07	7.25**				
	Tracking			0.63	0.35	.12	1.83
	Aiming			-0.03	0.35	-.01	-0.07
	Tracing			1.21	0.39	.18	3.12**
General Coordination		.06	6.30**				
	Tracking			0.10	0.31	.02	0.31
	Aiming			0.31	0.31	.07	1.00
	Tracing			1.13	0.35	.20	3.26**

*** $p < .05$, ** $p < .001$**

The pattern of results was very similar for all three subsections as for the total DCDQ scores, with CKAT explaining a significant 6-7% of the variance and tracing being the only significant predictor.

These regression models were then run with the clinical sample (see Table 2.7). The models were not significant for either the total DCDQ scores, or any of the subsections.

Table 2.7 Regression analysis of CKAT scores on DCDQ total and DCDQ subsections in clinical sample

Outcome	Predictors	R^2	F	B	Std. Error B	β	*t*
DCDQ Total		.06	0.64				
	Tracking			2.37	2.34	.22	1.01
	Aiming			-1.59	2.88	-.14	-0.55
	Tracing			3.38	4.02	.19	0.84
Fine Motor		.03	0.27				
	Tracking			0.72	0.86	.18	0.83
	Aiming			-0.51	1.06	-.13	-0.49
	Tracing			0.50	1.48	.08	0.34
Control During Movement		.04	0.38				
	Tracking			0.64	1.37	.10	0.46
	Aiming			0.06	1.68	.01	0.03
	Tracing			1.36	2.35	.14	0.58
General Coordination		.08	0.77				
	Tracking			1.02	0.88	.25	1.16
	Aiming			-1.14	1.08	-.27	-1.06
	Tracing			1.52	1.50	.23	1.01

* $p < .05$, ** $p < .001$

2.3.3 The relation between activity and participation

Finally, it was examined how performance at the activity level (MABC) translated into observed participation scores on the DCDQ. Standardised scores on the manual dexterity, aiming and catching, and balance subsections of the MABC were entered into a regression model as predictors, with DCDQ total score as the outcome in the school-based sample (see Table 2.8). Overall, the regression model predicted 14% of the variance in DCDQ total scores. The aiming and catching subsection score was the outcome that contributed significantly to this.

Table 2.8 Regression analysis of MABC scores on DCDQ total and DCDQ subsections in school-based sample

Outcome	Predictors	R^2	F	B	Std. Error B	*β*	*t*
DCDQ Total		.14	4.02*				
	MD			1.26	0.66	.22	1.91
	AC			1.14	0.51	.27	2.25*
	BAL			-0.38	0.54	-.09	-0.71
Fine Motor		.09	2.67				
	MD			0.45	0.22	.24	2.06*
	AC			0.24	0.17	.17	1.42
	BAL			-0.27	0.18	-.19	-1.53
Control During Movement		.16	4.72**				
	MD			0.28	0.28	.11	1.00
	AC			0.61	0.21	.34	2.90*
	BAL			0.01	0.22	.00	0.03
General Coordination		.12	3.42*				
	MD			0.54	0.24	.26	2.23*
	AC			0.29	0.19	.19	1.57
	BAL			-0.12	0.20	-.07	-0.60

* $p < .05$, ** $p < .001$; MD = Manual Dexterity; AC = Aiming and Catching; BAL = Balance

The aiming and catching scores also contributed significantly to the model for the control during movement subsection of the DCDQ, with the overall model sharing 16% of variance. The model with fine motor DCDQ scores as the outcome was not significant overall (accounting for 9% of the variance), but the manual dexterity score of the MABC contributed significantly to this. The general coordination scores on the DCDQ was significantly predicted by MABC scores (sharing 12% variance), and again the MABC manual dexterity scores significantly contributed to this.

In the clinical sample, the model for predicting overall DCDQ scores on the basis of MABC scores was not significant, although it shared 18% of the variance (see table 2.9). MABC scores also did not significantly predict the fine motor or general coordination DCDQ scores. However, there was a significant relation with the control during movement scores, where 29% of the variance in scores was shared with overall MABC performance. Contributing to this, the aiming and catching score on the MABC was a significant predictor.

Table 2.9 Regression analysis of MABC scores on DCDQ total and DCDQ subsections in clinical sample

Outcome	Predictors	R^2	F	B	Std. Error B	β	*t*
DCDQ Total		.18	2.13				
	MD			-0.27	0.46	-.11	-0.58
	AC			0.58	0.62	.18	0.93
	BAL			1.16	0.68	.34	1.69
Fine Motor		.07	0.69				
	MD			0.20	0.18	.22	1.10
	AC			-0.15	0.24	-.13	-0.63
	BAL			0.18	0.27	.14	0.66
Control During Movement		.29	4.00*				
	MD			-0.30	0.25	-.21	-1.19
	AC			0.68	0.34	.38	2.03*
	BAL			0.61	0.37	.31	1.66
General Coordination		.09	0.91				
	MD			-0.17	0.19	-.18	-0.93
	AC			0.05	0.25	.04	0.20
	BAL			0.37	0.27	.29	1.36

* $p < .05$, ** $p < .001$; MD = Manual Dexterity; AC = Aiming and Catching; BAL = Balance

2.4 Discussion

This study aimed to examine the relation between motor performance measured at the functional level (CKAT), the activity level (MABC) and the participation level (DCDQ). It was found that, within the general population, there were small-to-moderate significant relations between the different levels. This agrees with the ICF framework as the levels are clearly related but in a complex manner that means performance at one level cannot be used to predict outcomes at another level.

In this school sample, the tracing task on the CKAT was shown to be the significant predictor of the manual dexterity scores of the MABC. It could be that the sensorimotor requirements of the tracing task (accurate prospective control and continuous online corrections), are also required for the MABC manual dexterity tasks. For example, as well as the similar path tracing task on the MABC, the threading and placing pegs also require these sensorimotor skills. However, this pattern was not observed in the clinical sample of children. In both the school and the clinical samples, the functional tracking task and the balance activity subsection of the MABC were shown to be related. In agreement with this, Flatters, Mushtaq, Hill, Holt, et al. (2014) found that performance on the CKAT tracking task, but not the aiming or tracing tasks, significantly correlated with postural sway on a static balance task. This is possibly due to the fact that producing the fast, smooth movements on the tracking task requires greater postural stability.

The CKAT tracing task was the sole significant predictor of the scores on all the DCDQ subsections in the school-based sample, but this was not found in the clinical sample. The children's teachers filled out the DCDQ for the school-based sample, whereas the children's parents completed the questionnaire for the clinical sample. It may be that performance on the tracing task underpins many academic motor activities such as writing, which form the major part of the teacher's experience of the child's motor skills. On the other hand, parents would instead have much more experience of their child's motor abilities in other areas, such as during play. In order to examine this explanation, it would be necessary to get both the teachers and the parents to complete the DCDQ for the same group of children.

Looking at the relations between the MABC and the DCDQ, in both the school and the clinical sample, the aiming and catching tasks on the MABC predicted the control during movement scores on the DCDQ. Since three of the questions on this section of the DCDQ ask about throwing and catching ability, this is perhaps unsurprising. Similarly, that in the school sample, the manual dexterity subsection of the MABC was associated with the DCDQ fine motor score. However, this result was not repeated in the clinical sample.

These results support the use of frameworks such as the ICF model and Pennington's multiple deficit model for describing motor deficits, suggesting there is a complex relation between different levels of motor performance. This has a number of implications, in terms of screening, diagnosis and treatment of 'motor problems'. First, it supports the conclusion that there is no one test that will be able to identify 'poor motor performance' in its broadest sense, as children may have a deficit at the functional level, but this will not necessarily translate to a problem at the activity or the participation level. Similarly, two children who are measured as having a deficit in a particular activity may have this deficit for entirely different reasons, not least since nearly all activities involve other cognitive components such as attention or memory as well as a motor component.

The complexity of the links between these levels of deficit is also influenced by the contextual factors described in the ICF framework. A parent that provides extra support to help their child with their writing may result in a child with a functional motor deficit being able to find ways to compensate for this, and so not show a deficit at the activity level. If mediating environment and person factors can be identified, this would provide an alternative method of support to those children who may be struggling.

The current findings also have implications in terms of diagnosing clinical poor moor performance. From the results observed in this experiment, it can be suggested that the label of DCD is not particularly useful as constituted by the DSM V criteria. If strictly applied, the criteria seem to suggest both a functional and an activity level deficit are required for a diagnosis, although tests measuring motor skill activities are almost always used as a proxy for both in the research literature. Furthermore, if a functional and an activity level deficit are indeed required, this severely limits the number of children that could be diagnosed with this disorder and so gain access to treatment. The number of children with 'motor problems' who are diagnosed with co-occurring disorders raises further questions about the utility of the DCD construct described within DSM V.

The multiple deficit model framework (Pennington, 2006) suggests that it makes much more sense to consider deficits within a particular level of description. For example, it might be useful to identify and treat a specific sensorimotor deficit if it is found that the sensorimotor process is important for a number of activities (albeit that there is no direct map between the process and the activities). For example, a child with difficulties in the use of visual information for prospective control may subsequently have problems in the skill of writing. Thus, identification of a deficit in prospective control may justify a treatment regime that targets this control problem if it is established that such control is important for certain critical activities. For example, Waterman, Havelka, Culmer, Hill, and Mon-Williams (2015) found that Visuo-Motor Memory (assessed using the same underlying kinematic software as the CKAT) showed a predictive relation with academic attainment scores in reading and writing. Since these specific functional deficits have been found to link with observed academic outcomes, it seems reasonable to suggest that this specific functional skill should be targeted for children who show poor performance on the VMM construct as this might help their educational attainment.

Conversely, children might be identified because they show deficits in specific activities. The present results provide support for the task-oriented approach for intervention in such cases, as the functional deficit causing the activity limitation is generally far from clear. Rather, each activity limitation has its own pattern of aetiological and cognitive causation, and it is only by examining the patterns of deficit within a given task that the best paths for intervention can be revealed.

It is possible that it was the specific measures used in this study that resulted in the limited relation between performance at different levels. However, the functional measure collects data in a highly accurate objective way (Culmer et al., 2009), and the MABC and DCDQ are both widely used assessments, with the MABC in particular often used as a ‘gold standard’ (Schoemaker et al., 2006; Schoemaker, Flapper, Reinders-Messelink, & de Kloet, 2008). It may be that be using a functional measure that captured different sensorimotor skills, such as posture or prehension, would have resulted in greater overlap with the activity and participation level tasks. Likewise, using the BOTMP measure of activity, or the MABC checklist as a measure of participation. However, this in itself highlights that there is no measure of motor function that perfectly maps on to any given ‘activity of daily living’ (ADL), because ADLs are in themselves complex and require both cognitive and motor elements: which sensorimotor control processes are involved will vary between every different activity.

To summarise, ‘poor motor performance’ is an umbrella term that potentially encompasses a large range of functional sensorimotor control deficits, poor performance on motor activities, and lack of participation in life situations. However, poor performance at one of these levels does not necessarily predict behavioural problems at another level.

CHAPTER 3

THE RELATION BETWEEN BODY MASS INDEX AND MOTOR FUNCTION IN 4-5 YEAR OLD CHILDREN

3.1 Introduction

Obesity in childhood is a major global public health crisis, with an estimated 25% of children in the United Kingdom classified as obese, based on World Health Organisation classifications (Wang & Lim, 2012). With the short and long-term health risks associated with obesity, such as high blood pressure, type 2 diabetes, and respiratory problems, it is crucial to identify the mechanisms for weight gain in children (Karnik & Kanekar, 2012).

Children with poor motor performance are a group that may be particularly at risk of becoming obese. Indeed, a recent systematic review examining physical activity and fitness in children with Developmental Coordination Disorder (DCD), reported that out of eighteen studies examining the link between body composition and motor performance, thirteen had found a significant relation (Rivilis et al., 2011). However, it should be noted that all these studies measured motor performance at the activity level, and as discussed in Chapter 2, this means there are issues when claiming that it is motor deficits per se that are responsible for the observed relation.

Some of this research has been cross-sectional. Hands and Larkin (2006) split a group of children (n = 104, ages 5-8 years) into those scoring in the bottom 15% on either the Movement Assessment Battery for Children (MABC) (Henderson & Sugden, 1992) or the McCarron Assessment of Neuromuscular Development (MAND) (McCarron, 1997), both measures of motor skill that assess at the activity level. The children with poor motor performance were found to have a higher body mass index (BMI) than those in the nonpoor motor performance group. BMI, calculated on the basis of height and weight, is the most frequently used measure of weight status, and was used in 15 of the 18 studies in the systematic review (Rivilis et al., 2011). If measured correctly (i.e. by clinicians rather than parents themselves), and as long as age and sex appropriate charts are used to assess percentiles, BMI is argued to be an extremely useful proxy for weight status (i.e. not overweight, overweight or obese) (Himes, 2009).

In another cross-sectional study, D'Hondt et al. (2011) split their sample of 2932 children (aged 5-12 years) into healthy, overweight and obese groups based on the International Obesity Task Force (IOTF) age and gender specific cut-off points for BMI (Cole, 2000). Children with a BMI over the 85th percentile were classified as overweight according to the cut-points, and those over the 95th percentile were classified as obese. D'Hondt et al. (2011) then tested all the children's gross motor skills using the Körperkoordinationstest für Kinder (KTK) test of motor skills (again measured at the activity level of deficit) (Kiphard & Schilling, 1974), and found that whilst 20% of the healthy weight group scored below the 15th percentile on the KTK, this increased to 43.3% of those in the overweight category, and 70.8% in the obese category. D'Hondt et al. (2011) also reported in their study that the relation between weight status and motor performance became stronger with age. The overweight children aged 5-7 years showed relatively better motor performance than those overweight at 10-12 years.

The stronger link between obesity and motor skill in older children was then mirrored in longitudinal research by D'Hondt et al. (2013), which showed that the gap in motor performance (again measured by the KTK) between a group of 50 children who were overweight (BMI > 85th percentile) at age 6-10 years, and age matched controls (with BMI < 85th percentile), had widened two years later. Similarly, Joshi et al. (2015) found that the differences in BMI between a group of 103 children (initially aged 8-10 years) scoring under the 15th percentile on the short form of the Bruininks–Oseretsky Test of Motor Proficiency (BOTMP) (Bruininks, 1978), and 2175 children scoring over the 15th percentile, increased over the course of five years. Lopes et al. (2011) also found an increase in the relation between scores on the KTK and BMI in their longitudinal cohort of 285 children, measured annually from the age of 6 years until the children were 10 years old.

One explanation for this observed relation that is often cited is that children with poor motor performance choose to be less physically active because they lack confidence in their own abilities and may face embarrassment in front of their peers (Cairney et al., 2005; Hands, 2008; Schott et al., 2007). Since physical inactivity is a major risk factor in obesity (Hands & Larkin, 2002; Janssen et al., 2005), this may then lead to increased obesity being associated with poor motor performance (Stodden et al., 2008). This argument would suggest that a deficit in motor function is a causal factor, preceding obesity in these children. However, there is a counter-argument that children who are obese struggle to move (for example, rising out of a chair), and so may choose to avoid physical activity (Hills, Hennig, Byrne, & Steele, 2002). Avoiding taking part in opportunities to practice motor activities would then explain a decline in motor performance relative to their peers. In this case there may be no underlying motor deficit at the functional level. Instead, obesity is the preceding event that causes the reduction in the frequency of practice required for motor learning.

However, as shown in Chapter 2, disentangling this relation is hindered by the fact that motor performance has previously been measured at the activity level, and activities rarely just involve a motor element. Indeed, much of the previous research has used performance on activities such as dynamic balance and jumping to assess motor performance. These tasks involve moving body mass against gravity. Therefore, rather than an underlying functional motor control deficit, it may be that children who are obese simply have inadequate muscular strength in relation to their weight (Deforche et al., 2003; Hills et al., 2002; Riddiford, Steele, & Storlien, 1998). Likewise, poorer performance on dynamic balance tasks may be partly explained by the fact that obese children adjust their gait due to increased loading on the musculoskeletal system (Hills et al., 2002; Wearing, Hennig, Byrne, Steele, & Hills, 2006). This would explain why D'Hondt et al. (2011) found the strongest effects between motor performance and BMI on the KTK hopping task, and why Castetbon and Andreyeva (2012), in a sample of young children (5100 children aged

4 years, and 4700 children aged 4-5 years), found that the only differences between the obese (BMI > 95^{th} percentile) and the normal weight children (BMI < 85^{th} percentile) were on the hopping and jumping tasks of the BOTMP and MABC. No significant differences were found for the other tasks, such as skipping, or fine-motor skills such as building a tower and copying shapes. Therefore, it is particularly difficult to attribute this to functional motor deficits.

There has been some research focusing on fine motor activities (activities using small groups of muscles such as the hand (McCarron, 1997)), which are not so affected by factors such as muscular strength in the lower limbs. D'Hondt, Deforche, De Bourdeaudhuij, and Lenoir (2008) found that out of a group of 540 children, aged 5-12 years old, the obese children were worse at a manual dexterity task involving placing pegs compared to children in the overweight and normal weight groups (based on BMI percentiles). Gentier et al. (2013) found, using the BOTMP motor test, that a group of 34 obese children (7-13 years old) had poorer 'fine motor precision' (involving drawing lines and folding paper), and 'manual dexterity' (transferring pennies into a box) than aged matched controls of a normal weight. However, there were no differences observed in the 'fine motor integration' task (involving copying a square and a star).

However, these assessments are still measuring at the level of activity, and as was shown in Chapter 2, this does not mean that these children necessarily have a deficit in motor control at the functional level. Since each activity requires different underlying sensorimotor processes, as well as different cognitive processes, it is unsurprising that performance on these different 'fine motor' activities are related to different extents to BMI. Although it is clearly not possible to have a completely isolated motor task, using measures that tap into specific sensorimotor control functions, whilst attempting to reduce cognitive requirements will allow greater understanding of the relation between motor function and obesity.

A final problem with previous studies is that many of the assessments of the motor activity are scored on very limited scales. For example, one test on the BOTMP used in a number of the previous studies (Castetbon & Andreyeva, 2012; Gentier et al., 2013; Joshi et al., 2015) requires the number of 'correct' steps out of six to be scored, giving only seven possible scores on which to try to differentiate all the children's performance, and giving no information about the movement quality. Likewise, the KTK, used in some of the other previous research (D'Hondt et al., 2011, 2013; Lopes et al., 2011) uses mostly pass/fail scoring for each task. This is a common theme amongst many tests which aim to measure motor performance, but is a problem since motor abilities are on a continuum, they are not present or absent (Culmer et al., 2009). Whilst this may be suitable for identifying those with severe functional difficulties, this makes it difficult to be able to draw reliable conclusions about any potential relations with obesity, and indeed, with other outcomes (Cliff et al., 2012; Culmer et al., 2009). There is therefore, a need to examine the relation between obesity and underlying sensorimotor function.

For this study, two tasks measuring motor function were selected. Firstly, the Clinical Kinematic Assessment Tool (CKAT) (Culmer et al., 2009). The CKAT is a computerised assessment of fine motor 'pen skill' control, involving using a stylus to interact with a tablet computer in a tracking task, an aiming task, and a tracing task. Overall score on the CKAT has been used as a measure of fine motor control at the activity level (Flatters, Hill, et al., 2014; Flatters, Mushtaq, Hill, Holt, et al., 2014; Hill et al., 2016), and in addition, since the three tasks individually tap into different sensorimotor control processes (Culmer et al., 2009), the CKAT can also be used to measure sensorimotor control function. The CKAT has been used previously in children aged 4-11 years, and within this age range has been shown to reliably differentiate children on the basis of age and sex (Flatters, Hill, et al., 2014). Therefore, it provides an ideal measure to be able to assess whether there is an underlying link between obesity and sensorimotor control.

Postural stability is a further functional motor ability that may be specifically linked to obesity. Postural stability is a skill that underpins many other motor activities. Even in infancy, the ability to maintain a stable trunk is a pre-requisite for developing reach-to-grasp behaviours (de Graaf-Peters, Bakker, van Eykern, Otten, & Hadders-Algra, 2007). By adulthood, there is a large relation between postural sway and obesity - Hue et al. (2007) found, in a group of 59 adult males (aged 24 – 61 years), that weight (controlling for height) accounted for over 50% of the variance in centre of pressure speed, objectively measured on a force platform (with eyes open and eyes closed). However, Goulding, Jones, Taylor, Piggot, and Taylor (2003) examined a sample of 93 children aged 10 – 21 years old and found that, although balance as measured by the BOTMP balance test was significantly worse in boys who were above the 85th percentile for BMI, there was no significant difference in the two computerised assessments of balance and postural sway. The postural sway measure here assessed limits of stability, with participants asked to lean in a given direction without losing balance. However, the authors reported that this measure may have not been subtle enough to pick up any differences. Postural sway therefore, makes an interesting functional motor outcome measure to examine in relation to obesity. A postural rig developed by Flatters, Culmer, Holt, Wilkie, and Mon-Williams (2014) offers an ideal way to measure this, and has been used as a proxy for gross motor control in children aged 3-11 years (Flatters, Mushtaq, Hill, Holt, et al., 2014; Flatters, Mushtaq, Hill, Rossiter, et al., 2014).

These measures need to be examined in children as part of a longitudinal study, and this needs to begin early enough so that any emerging relation between motor control and obesity can be distinguished. Previous longitudinal research observed a BMI/motor performance relation at the baseline (D'Hondt et al., 2013; Joshi et al., 2015; Lopes et al., 2011), and therefore, had no opportunity to discover whether obesity preceded poor motor performance, or whether poor motor performance preceded obesity. This was potentially because the samples all involved children over the age of six. In a younger sample of pre-school children (3-4 years old, n = 198) Williams et al. (2008) found no relation between BMI and motor performance measures involving six locomotion tasks and six object control tasks. However, since this study was cross-sectional and these children were not followed up, it is impossible to know whether further relations would have developed later. It seems then that there is a real need for a longitudinal study, starting at a young age, to try and unpick whether motor deficits, measured at the functional level, lead to obesity, or whether obesity leads to poorer motor function.

Therefore, this study utilised data from the Born in Bradford 1000 (BiB1000) cohort study. The BiB1000 longitudinal cohort was established to investigate the causes and influences surrounding childhood obesity (Bryant et al., 2013). As part of this, BMI data could be accessed for these children that was collected in the year of entry into UK primary school (age 4-5 years), as part of the National Child Measurement Programme (NCMP) (Health and Social Care Information Centre, 2014). The NCMP recorded the data of over one million children in reception (including the BiB1000 children) and year 6 in 2013/14, 94% of all eligible schoolchildren in these year groups. Nationally, 22.5% of children in reception year were classified as overweight or obese, and 9.5% were obese. Children from disadvantaged backgrounds were found to be at a higher risk of obesity, as were children from South Asian backgrounds (Health and Social Care Information Centre, 2014). As a city, Bradford is the 26th most deprived local authority in the UK according to the Index of Multiple Deprivation 2010 (ONS, 2011), and has an extremely multi-cultural population – 20% of the population describe their ethnicity as Pakistani, and this rises to 85% in some of the inner city areas (ONS, 2012). This setting therefore gives a unique opportunity to examine the link between obesity and motor function, in a population that is high risk for weight-related issues.

In addition, CKAT data were available for the BiB1000 children as these were collected as part of a school-readiness set of assessments taken, also during reception year, as part of the wider Born in Bradford longitudinal study (Wright et al., 2013). This meant that fine motor control data were able to be linked to the NCMP data in the BiB1000 cohort. In order to examine these children's postural sway, a sub-sample of the BiB1000 cohort were re-visited, again in their reception year of schooling.

Therefore, the aims of this study were to examine whether, at 4-5 years old, there is a relation between obesity and functional motor control (specifically, sensorimotor control and postural sway). In addition, the secondary aim was to establish the baseline for a prospective longitudinal study to examine how this relation emerges over time. Since differences in body composition have been found between the Pakistani and White British children up until the age of 2 years, within the BiB1000 population (Fairley et al., 2013), and differences in the relation between motor skills and obesity for males and females have been reported (Cairney et al., 2005; Lopes et al., 2011; Schott et al., 2007), analysis was conducted to examine these groups separately.

3.2 Method

3.2.1 Participants

The children in this study were part of the BiB1000 cohort, itself part of the larger Born in Bradford (BiB) longitudinal study (Bryant et al., 2013; Wright et al., 2013). The BiB1000 was established to explore the factors relating to childhood obesity. The BiB1000 cohort is made up of 1707 singleton children, and 28 sets of twins, making 1763 children in total, all of whom were born between 2008 and 2009 (see Bryant et al. (2013) for a full description of cohort characteristics). Permission to use the BMI and CKAT data on these children was granted by the BiB Executive.

In May and June 2014, 24 schools were revisited to collect postural sway data. Only BiB1000 children took part in this, and in selecting which schools to visit, those with the highest numbers of BiB1000 children were given priority. These schools were contacted, and if they agreed to take part, the school were given information letters to send to the parents of the children involved one week before the school was visited. These letters also gave information on how to withdraw their child from the study. All aspects of this consent procedure were granted from the University of Leeds Ethics and Research Committee (ref: 14-0105), and this included a full risk assessment.

3.2.2 Materials and procedure

3.2.2.1 Body mass index

Height, weight and BMI were collected in Reception year by school nurses as part of the National Child Measurement Programme (Health and Social Care Information Centre, 2014). Age related percentile cut-offs for population use (Public Health England, 2012), based on the UK90 reference tables (Cole, Freeman, & Preece, 1995) were used to classify children as either not overweight (< 85th percentile), overweight or obese (> 85th percentile), and obese (> 95th percentile).

3.2.2.2 Sensorimotor control

At the point the children entered their first year of formal schooling (age 4-5 years), 75 Bradford Primary schools took part in the 'Starting Schools' set of assessments, which included the CKAT measure of fine motor control. All children in the Reception classes took part (whether they were part of the BiB cohort, the BiB1000 cohort, or neither). Study administrators went into the schools, and completed the CKAT (as well as two measures of vocabulary and letter identification not discussed here) with children on a one-to-one basis, in a session lasting approximately 30 minutes. These data were collected between September 2013 and July 2014.

The CKAT battery was run using Kinelab software (see Culmer et al. (2009) for details of underling architecture) on a tablet computer (Hewlett-Packard EliteBook 2760p tablet PC, screen size: 261x163 mm, 1200x800 pixels, 60 Hz refresh rate). A pen shaped stylus was used as an input device in order interact with the tracking, aiming tracing tasks.

For the tracking task, the outcome was the average root mean square error (RMSE) from the centre of the moving dot, to the point of the stylus. For the aiming task, the primary outcome was the average movement time (MT) between one dot to the next, and for the tracing task, average accuracy (between the stylus and the closest centre-line point of the path), adjusted for time taken, was taken as the outcome (for further detail and justification of these outcomes, see Flatters, et al. (2014)). These outcomes were then reciprocally transformed to result in acceptable skewness and kurtosis, and standardised against all the other children to produce z scores. These three z scores were used individually as outcomes of sensorimotor control. In addition, a mean of these three z scores was taken as an overall outcome measure of fine motor control ability. Those children in the bottom 15th percent for overall fine motor control were classified as the 'poor fine motor control' group, and those in the top 15th percent were classified as the 'good fine motor control' group.

3.2.2.3 Postural sway

In a quiet room away from distractions, each child was asked to stand on a custom built system which used the Nintendo Wii Fit balance board to measure of centre of pressure (captured at 60 Hz). This system has previously been validated (Flatters, Culmer, et al., 2014), and used as a measure of gross motor control and postural sway with children aged 3-11 (Flatters, Mushtaq, Hill, Holt, et al., 2014).

The child was asked to stand on the balance board with their feet shoulder width apart. They were instructed to stand as still as they could, for 30 seconds with their eyes closed, and 30 seconds with their eyes open and fixated on a point 1m away at eye level. During each of these trials the child was monitored by the researcher to ensure compliance.

The path length subtended by this over each 30 second trial was calculated (in mm) (see Flatters, Culmer, et al., 2014; Flatters, Mushtaq, Hill, Holt, et al., 2014; Flatters, Mushtaq, Hill, Rossiter, et al., 2014). The scores were square root transformed, and then z scores was then produced for both conditions across the whole sample (eyes closed and eyes open). These two z scores were averaged in order to get the continuous outcome postural sway (PS). In addition, those children in the in the highest 15th percent for overall postural sway were classified as the 'large postural sway' group, and those in the smallest 15th percent were classified as the 'small postural sway' group.

3.2.2.4 Data Linkage

BMI data from the NCMP study was linked via the Born in Bradford database to each child's BiB1000 identification number, with valid BMI data recorded for 1232 BiB1000 children (548 male). Of these children, 460 (35%) were White British, and 613 (46%) were Pakistani. 830 children had valid CKAT data from the 'Starting Schools' project, and from these two data collections, valid data on both BMI and fine motor control was able to be linked for 820 children.

Postural sway data was collected for 272 children, with 245 children's data able to be linked to their BMI data. There were 5 extreme outliers ($|z|>3$) for this outcome, but since it was impossible to determine whether these were genuine results, due to participant non-compliance, or technical error, subsequent analysis using the continuous outcome measure for postural sway was run with and without these data points included. Data for 245 children could be matched on the BMI and postural sway measures (n=240 without outliers included).

3.3 Results

Descriptive statistics for fine motor control (whole sample, poor fine motor control group and good fine motor control group) and postural sway (whole sample, high postural sway group and low postural sway group) are reported in Table 3.1, along with descriptive statistics for BMI. BMI categories were split according to age and sex appropriate cut-off points (Public Health England, 2012). The 'not overweight' group were those children with a BMI under the 85^{th} percentile. The 'overweight or obese' sample were those with a BMI over the 85^{th} percentile, and those with a BMI over the 95^{th} percentile were categorised as obese.

Table 3.1. Descriptive statistics for BMI, fine motor control and postural sway, for continuous outcomes and categories

Measure	Category	n	mean	Standard Deviation
BMI	All	1232	15.97	1.65
	Not overweight	901	15.20	0.95
	Overweight or obese	331	18.07	1.31
	Obese	133	19.28	1.28
Fine Motor Control	All	830	0.03	0.68
	Poor fine motor control	120	-1.00	0.23
	Good fine motor control	118	1.17	0.39
Postural Sway	All	252	-0.07	0.75
	High postural sway	30	1.86	0.89
	Low postural sway	21	-1.07	0.11

Looking at the BMI for this sample, 26.87% of the sample were overweight, and 10.80% of the sample were obese. This is slightly higher than the national averages reported by the NCMP, where 22.5% of children were classified as overweight or obese, and 9.5% were classified as being obese.

It was first examined whether those children in the extreme categories for fine motor control or postural sway would differ in their BMI. The top 15% of all scores for fine motor control were taken as the 'good fine motor control' group, and those children with the bottom 15% of scores were classified as the 'poor fine motor control' group (see Figure 3.1).

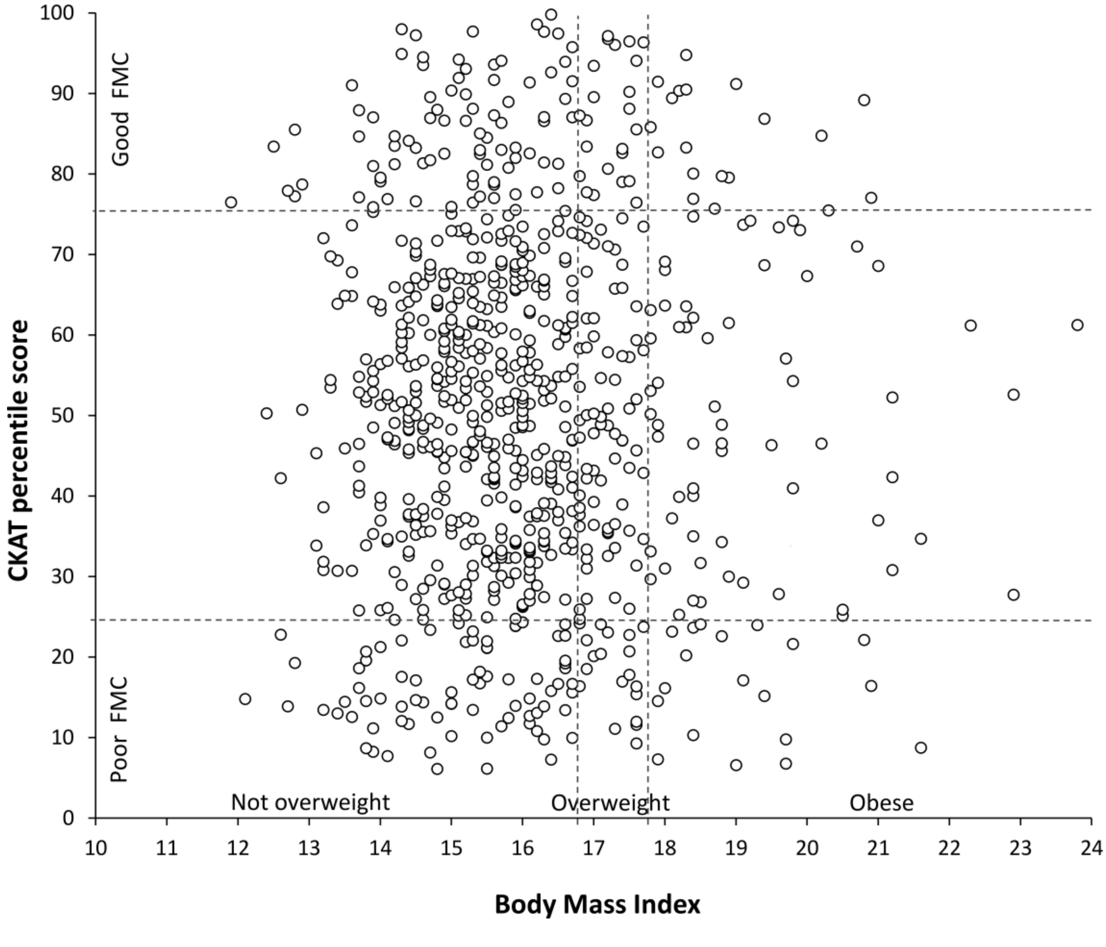

Figure 3.1 Plot showing the distribution of percentile scores on CKAT and BMI

FMC = fine motor control; Good FMC = top 15% of scores. Poor FMC = bottom 15% of scores. For BMI, sample split into 'not overweight' (BMI < 85^{th} percentile), overweight (85^{th} – 95^{th} percentile) and obese (> 95^{th} percentile)

Independent samples t-tests were then run, in order to examine group differences between the children with poor and good fine motor control in their BMI scores. There was not a significant difference between the good fine motor control (M = 16.05, SD = 1.68) and the poor fine motor control (M = 16.10, SD = 1.68) conditions; $t\,(234) = 0.22$, $p = .83$.

This was then repeated looking at the difference in BMI between children with the highest amounts of sway on the postural task (largest 15% of scores) who were categorised as the 'high postural sway' group, and those with lowest amounts of sway (smallest 15% of scores) who were categorised as the 'low postural sway' group (see Figure 3.2).

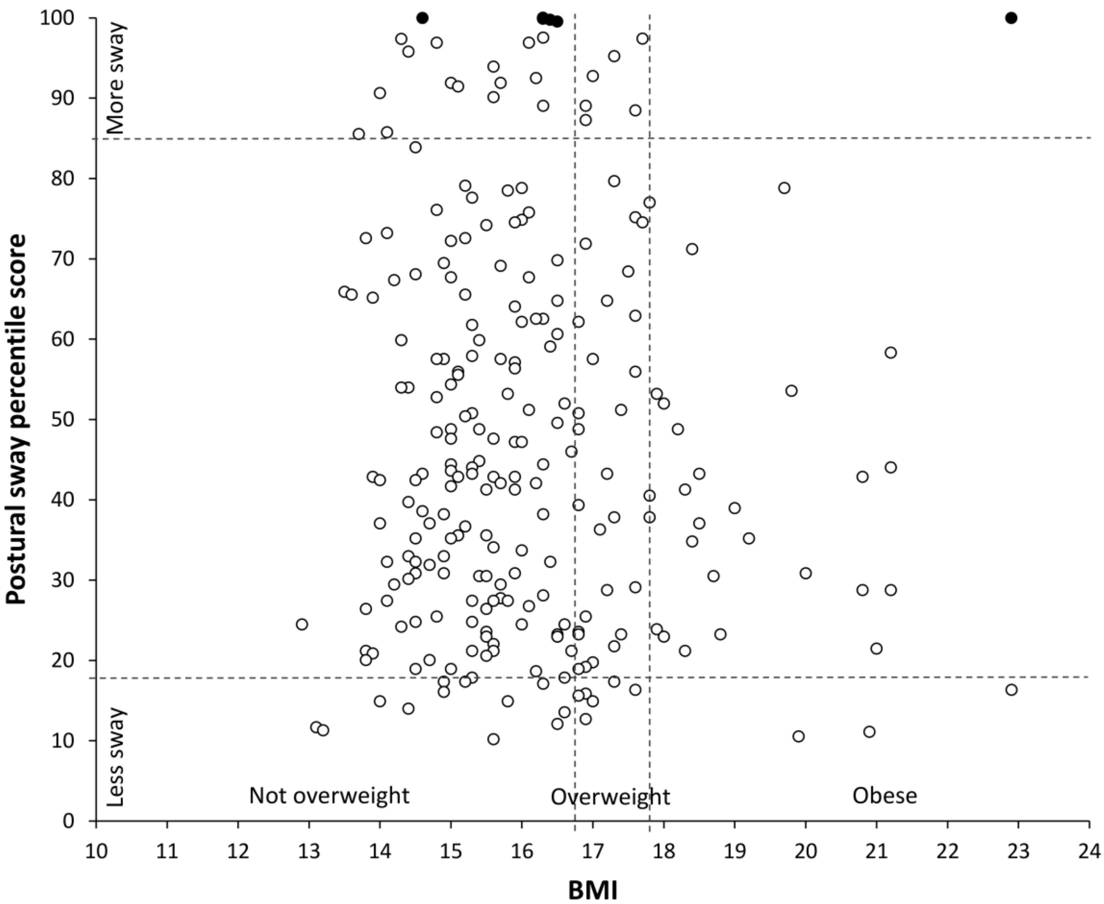

Figure 3.2 Plot showing distribution of postural sway percentile scores and BMI

For postural sway, low sway = smallest 15% of scores. High sway = largest 15% of scores Points classified as outliers (|z| > 3) are highlighted in black. For BMI, sample split into 'not overweight' (BMI < 85th percentile), overweight (85th – 95th percentile) and obese (> 95th percentile)

There was also not a significant difference in the scores for high postural sway (M = 15.72, SD = 1.21) and low postural sway (M = 16.51, SD = 2.39); *t* (42) = -1.39, *p* = .17.

It was then examined whether those in the 'not overweight' category did not differ from those in the obese category (> 95th percentile) on their fine motor control score. No significant difference in fine motor control score between those in the not overweight category (M = 0.03, SD = 0.66) and those in the obese category (M = -0.02, SD = 0.74) were observed; *t* (120.62) = 0.67, *p* = .50 (Greenhouse-Geisser correction used).

With outliers included in the postural sway sample, there was no significant difference in the amount of postural sway between the not overweight children (M = 0.04, SD = 0.91) and the obese children (M = -0.22, SD = .86); *t* (202) = 1.43, *p* = .15. With the outliers excluded, there was a significant difference between children in the not overweight group (M = -0.05, SD = .73) and children in the obese group (M = -0.36, SD = 0.48); *t* (50.79) = 2.93, *p* = .03 (Greenhouse-Geisser correction used). This indicates that the children who were obese had smaller amounts of postural sway than the children who were not overweight.

The links between BMI and the functional measures of motor control were then examined. In addition, it was examined whether there were any differences in this relation when it was split by gender, ethnicity, or both. Only the two largest ethnic groups were examined: Pakistani (49.75%) and White British (37.33%), since the numbers of children in other ethnic groups were too small.

Looking at the children as a single group, a regression analysis was run with the sensorimotor control variables (tracking, aiming and tracing) as the predictors, and BMI as the outcome. This was done first for the sample as a whole, then split by ethnicity, gender, and then ethnicity and gender (Table 3.2).

Table 3.2 Results for regression analysis run with sensorimotor control variables (tracking, aiming and tracing) as the predictors, and BMI as the outcome

Sample split by	Group	n	F	*p*	*r*
All	All	820	0.04	.84	.01
Ethnicity	Pakistani	432	0.74	.53	.07
	White British	289	0.03	.99	.02
Gender	Male	399	0.12	.95	.03
	Female	410	0.72	.54	.07
Ethnicity and gender	Pakistani Male	200	0.76	.52	.11
	Pakistani Female	225	0.17	.92	.05
	White British Male	145	0.20	.89	.07
	White British Female	141	0.24	.87	.07

The regression models were not significant for either the whole sample, or when split by ethnicity, gender, or both. The largest observed correlation between BMI and the CKAT variables was observed in the male Pakistani children, although this was still a small effect.

The relation between BMI and postural sway was then examined. A regression analysis was run with postural sway as the predictor variable, and BMI as the outcome variable. This was analysed for the whole sample, and then split by ethnicity, gender, and ethnicity and gender (Table 3.3). In addition, these regression models were run with and without the five extreme outliers included ($|z| > 3$).

Table 3.3 Results for regression analysis run with postural sway as the predictor, and BMI as the outcome.

Outliers	Sample split by	Group	n	F	*p*	*r*
Included	All	All	245	0.47	.49	.00
	Ethnicity	Pakistani	153	0.04	.84	.02
		White British	71	0.24	.63	.06
	Gender	Male	116	3.38	.07	.17
		Female	129	0.23	.63	.04
	Ethnicity and gender	Pakistani Male	74	3.66	.06	.22
		Pakistani Female	79	2.25	.14	.17
		White British Male	30	0.25	.62	.10
		White British Female	41	1.09	.30	.17
Excluded	All	All	240	1.66	.20	.08
	Ethnicity	Pakistani	151	1.05	.31	.08
		White British	68	.07	.80	.03
	Gender	Male	114	3.16	.08	.17
		Female	126	0.07	.80	.02
	Ethnicity and gender	Pakistani Male	74	3.66	.06	.22
		Pakistani Female	77	0.32	.57	.07
		White British Male	28	1.02	.32	.20
		White British Female	40	1.08	.30	.17

Again, none of the models were significant, with or without the outliers included. The male Pakistani children had the highest correlation between BMI and postural control, followed by the male White British children, with the smallest correlation between postural sway and BMI observed in the Pakistani female children.

3.4 Discussion

The relation between BMI and functional motor skills was examined in a large cross-sectional sample of 4-5 year old children in their first year of schooling. The aim was to examine firstly, whether any relation could be seen at this age between obesity and functional motor skills, and secondly, to establish a prospective longitudinal sample that will examine this relation as the children age.

No relation was found between BMI and either sensorimotor control or postural sway when examining the measures as continuous variables. Likewise, children in the bottom and top 15% for either overall fine motor control or postural sway did not vary on their BMI. The pattern of results are consistent with the previous research showing that the strength of the relation between weight status and motor skills is weaker in younger age groups (D'Hondt et al., 2013; Joshi et al., 2015; Lopes et al., 2011), and that children aged 3-4 years had showed no relation between motor skills and obesity (Williams et al., 2008). Here, using objective measures, it has been shown that at the age of their first year of schooling, there is not yet a relation between the children's BMI and functional motor ability.

Whilst it is often argued that children with poor motor function will gain weight through their lack of physical activity (caused by their lack of confidence in their own skills), it could equally be the case that the obese children are the ones who do not partake in opportunities to improve their motor function through practice. Both these mechanisms could also be correct, and the relation may well be circular – children with poor motor function avoid physical activity and become more obese, which in turn prevents them choosing to take part in opportunities to improve their motor function, and so on. Although this cannot be resolved through the study here, this study does provide the ideal opportunity to disentangle these theories through a prospective longitudinal study. By following these children as they get older and repeating these measurements, it can be observed whether the children who are obese now, but currently do not show any deficits in their functional motor ability, do comparatively worse in their motor function compared to their peers when assessed at a later time point. Likewise, it can be examined whether the children with poor motor function in this study, gain comparatively more weight.

There are other factors which may influence both obesity and motor coordination. For example, inadequate nutrition in the early years has been linked to later obesity (Sothern, 2004), and this has also been linked to poorer motor proficiency (Kitsao-Wekulo et al., 2013). Therefore, it may only be those children who are obese through excess consumption of unhealthy foods, rather than excess consumption of food that would otherwise be regarded as healthy, that may also show poorer motor outcomes. By examining data from the BiB1000 cohort in the future, along with dietary information collected as part of data on these children's diets that were collected at birth and age 2 (Bryant et al., 2013), possibilities such as this can be explored.

This research benefited from using measures of motor function, rather than performance on specific motor activities, some of which may well have been more influenced by, for example, effects of muscular strength relative to weight than sensorimotor deficits. This bias may explain a number of the results in previous research. For example, why in the study by Castetbon and Andreyeva (2012), the only significant differences on motor tasks between those in the obese category and those in the normal weight category, were the skills directly impacted by increased body weight – hopping and jumping. Again, it is only by tracking the children in our study that it can be assessed how far these results were simply down to the 'motor' assessments used, and how far obese children actually have underlying motor control difficulties at the functional level.

One limiting factor here is that BMI was used as a proxy for weight status. BMI has been criticised as being unreflective of actual levels of adiposity, since it highly correlates with both lean and fat mass without being able to distinguish between them (Wells, 2001). This means that two children with equal BMI scores may have completely different levels of body-fat. For example, South Asian children typically show lower muscle mass and higher proportions of body fat (Saxena, Ambler, Cole, & Majeed, 2004; Yajnik et al., 2003), and this may not be reflected in BMI status. In order to take this into account, the analysis here was run with the Pakistani and White British children separately. Although there were no significant differences observed when splitting the children by ethnicity, there was a trend that the relation between motor control and BMI was larger for the Pakistani boys than the White British boys, whereas the weakest relation was found in the Pakistani girls. Therefore, during subsequent follow-up of this sample, it will be interesting to observe whether this pattern persists. It would also be interesting to compare BMI in these children with more accurate measures of fat mass - for example, by calculating measures of fat mass index and fat-free mass index (Wells, 2001), and this could give more reliable measures in future time-point measures.

The results here would suggest that the relation between sensorimotor function and obesity has yet to be established in children at point of entry to primary school. By following this group of children, the complex relation between obesity and motor function can be examined, without the limiting factors associated with the measures used in previous studies. By exploring these mechanisms, it is hoped that paths for intervention will be revealed, to try and minimise the negative health consequences of obesity.

CHAPTER 4

SENSORIMOTOR CONTROL AND ACADEMIC ATTAINMENT IN PRIMARY SCHOOL CHILDREN

4.1 Introduction

In order to succeed at primary school (ages 4-11 years) in the UK, children must do well on assessments of reading, writing and mathematics (Department for Education, 2014). However, it has been suggested that children with poor motor performance may struggle with these outcomes compared to their peers (Grissmer et al., 2010; Zwicker et al., 2012). Children with Developmental Coordination Disorder (DCD) frequently show co-morbid difficulties with language disorders (Archibald & Alloway, 2008; Leonard & Hill, 2014), reading difficulties (Alloway & Archibald, 2008; Alloway, 2007; Lingam et al., 2010) and mathematical problems (Alloway, 2007; Pieters, Desoete, Van Waelvelde, Vanderswalmen, & Roeyers, 2012), severely limiting their academic success at school. These co-occurring difficulties have contributed to the argument that motor ability is fundamentally related to cognitive and language development.

However, the difficulty with basing conclusions on studies using clinical populations is that they suffer from referral and ascertainment biases. Those children that are referred to specialised services tend to be those with the most complex and severe problems (Low, Cui, & Merikangas, 2008). Therefore, those children with functional motor control difficulties that end up being diagnosed with the clinical label of DCD may not be representative of the larger number of children with functional motor control difficulties who do not get referred to clinical services ('referral bias'). In addition, those children that have been diagnosed with difficulties in one area are more likely to be screened for difficulties in another area compared to the general population. Therefore, there is likely to be a higher proportion of co-occurring difficulties diagnosed amongst this clinical group ('ascertainment bias'). Both of these biases could lead to an overestimation of the relation between motor control and academic attainment. This means that it is not possible to extrapolate from clinical studies and conclude that motor difficulties and attainment are linked in the general population.

There is, however, convergent evidence that suggests a relation between motor control and educational attainment across the population. A number of studies have examined this relation in large cohort samples and have suggested that motor skills (measured at the activity level) and academic attainment are linked in the general population. For example, Grissmer, Grimm, Aiyer, Murrah, and Steele (2010) set out to identify kindergarten readiness factors from six longitudinal data sets. Grissmer et al (2010) incorporated motor skill measures from three of the longitudinal data sets and suggested that fine motor skills were a "strong predictor of later achievement". The three longitudinal samples used by Grissmer et al (2010) were the Early Childhood Longitudinal Survey– Kindergarten cohort (ECLS-K), the British Birth Cohort Study (BCS), and the National Longitudinal Survey of Youth (NLSY).

The Early Childhood Longitudinal Survey– Kindergarten Cohort (ECLS-K), (also reported in Son and Meisels (2006)) was a sample of 12,583 children of kindergarten age. It was concluded from baseline measures (taken at a mean age = 5.42 years) that fine and gross motor ability at kindergarten predicted reading and mathematics achievement in the first year of formal schooling (on average 18.4 months later). The motor abilities were assessed via the Early Screening Inventory–Revised (ESI-R) tool (Meisels, Marsden, Wiske, & Henderson, 1997). Moreover, Luo, Jose, Huntsinger, and Pigott (2007) showed that the fine motor scores from the ESI-R assessment continued to predict mathematics achievement in the ECLS-K cohort for the next two years of schooling (average 6 and 7 years old).

In the BCS cohort, 13,135 children were assessed on three drawing tasks at 5 years old – copying eight shapes, human figure drawing and profile drawing – all of which were scored as pass/fail items (Grissmer et al., 2010). Scores on each of these three tasks were then compared to national attainment scores for reading and mathematics at age 10 years. It was found that the copying task and the human figure drawing task both significantly predicted later academic achievement, with the profile drawing task not being significant.

Motor ability in the NSLY cohort (n = 12,686, under 4 years old) (Grissmer et al., 2010) was assessed via a parental questionnaire (Mott, Baker, Ball, Keck, & Lenhart, 1995). Depending on the child's age, 15 developmentally appropriate questions about whether the child had reached a specific motor milestone were asked of the mother of each child (scored yes/no). The children were then assessed on the Peabody Individual Achievement tests of Reading and Mathematics skills at age 5-6 years, and scores on the parental motor questionnaire were found to significantly predict both reading and mathematics ability.

In a further longitudinal study, Dinehart and Manfra (2013), assessed 3234 children in preschool (mean age 5.21 years) on the Learning Accomplishment Profile–Diagnostic (LAP-D) (Nehring, Nehring, Bruni, & Randolph, 1992). The LAP-D results in a fine motor manipulation composite score (based on 28 tasks, such as building structures with blocks, weaving string, folding paper), and a fine motor writing composite (based on 31 tasks, such as drawing objects and letters). All these tasks were scored as correct or incorrect, and raw scores were number of correct items for each category. It was found that both fine motor manipulation and fine motor writing predicted perfomance on standardised school assessments two years later, and that fine motor writing predicted academic outcomes to a greater extent than the manipulation tests.

In a smaller cross-sectional study focusing on older children, Sortor and Kulp (2003) assessed motor performance via the Beery-Buktenica Developmental Test of Visual-Motor Integration (VMI) on 155 children aged 7-10 years old, and found that those children falling in the highest quartile on the VMI scored significantly better on the mathematics and reading scores from the Stanford Achievement Test (Harcourt Educational Measurement, 1995).

There is clearly converging evidence of a relation between motor control and educational attainment. Nevertheless, there are limitations to the conclusions that can be drawn from the existing studies. On the one hand, these studies highlight the importance of movement skills within primary school education. These studies have good face validity with the observation that movement skills are central to a child's development within the primary education system (from cutting out shapes through to learning to write). On the other hand, similar to the issues identified in Chapter 2, the studies have used complex measures of motor activity that have higher-order cognitive demands as well as sensorimotor elements. The assessments themselves are subject to measurement issues and typically use pass/fail scoring techniques that are useful for identifying children with difficulties but fail to distinguish capability in more able children (and thus introduce ascertainment bias despite the study being population based). Finally, the assessments tend to collapse 'motor deficit' into a single construct which makes it hard to understand what sensorimotor control problems might relate to poor educational attainment.

For example, many tasks used in the longitudinal assessments reviewed by Grissmer et al. (2010) are not purely 'motor' in nature. Clearly, it is not possible to completely isolate the sensorimotor system since all tasks are reliant to a certain extent on cognitive abilities. For example, whether the child understands what they have been asked to do will affect their performance on any assessment. However, some tasks, such as drawing a human figure, are heavily dependent on knowledge about human anatomy. In fact, this task is often used as a measure of overall cognitive function rather than motor ability (Ter Laak, De Goede, Aleva, & Van Rijswijk, 2005). It is difficult, therefore, to determine whether the drawing task is predictive because it contains a number of the complex elements required for academic success or whether it reflects an underlying relation between motor function and academic attainment.

There are a number of additional issues with the tools used in the longitudinal studies. For example, the ESI-R involves a number of gross motor skills (balancing, hopping, skipping and walking backwards), and fine motor skills (building a gate, drawing a person, copying five shapes), all scored on binary scales. But motor control ability is on a continuum and doesn't fit neatly into pass/fail categories (Flatters, Hill, et al., 2014). Therefore, measures that only assess a motor skill as pass/fail, or on a limited scale, may be able to identify children with severe difficulties but do not have the ability to reliably differentiate between children (Culmer et al., 2009). The ability to differentiate all levels of skill is critically important when establishing a dimensional relation given that 'motor skill' is dimensionally rather than dichotomously distributed (Leonard & Hill, 2014).

A further issue with the pass/fail type assessment scales is that they are subject to measurement problems. This is because they simply measure the end-product of the motor activity, and the difference between a pass or fail can often be based on very marginal features that are subject to a high degree of subjectivity. For example, in one of the tests of motor performance (the VMI), a diamond shape that is drawn with greater than 60 degree angles would be marked as incorrect, whereas an almost identical shape with slightly smaller angles would be marked as correct. Therefore, a huge amount of dimensional detail is missed about how the child actually performs the movement.

The final issue with the longitudinal studies reported in Grissmer et al. (2010), is that the assessments of motor ability are based on composite measures of performance on very different motor skill activities. For example, the ESI-R scores were grouped into composite 'gross' and 'fine' outcome measures. However, as highlighted in Chapter 2, people's ability on one specific motor skill does not necessarily determine their ability on other motor skills. For example, Haga, Pedersen, and Sigmundsson (2008) found very low correlations between performance on eight motor skill tasks (including balance, jumping, posting coins, threading beads) from the MABC (Henderson & Sugden, 1992). This is also seen at the functional level of deficit, whereby Flatters, Mushtaq, et al. (2014) found that fine motor pen-skills and postural stability only shared around 10% of the variance in scores. Therefore, different motor tasks require different specific underlying motor control processes (Stöckel & Hughes, 2015), and it is not useful to create composite scores from different tasks.

In short, there is converging evidence from clinical populations and population based research suggesting that motor performance and academic attainment may be linked. However, the issues inherent in the way these motor abilities are assessed means this has not been shown conclusively. It is only through taking objective, continuous measures of sensorimotor control processes at the functional level that specific relations with academic attainment can start to be teased out. CKAT offers a solution to the need for objective kinematic measurements in large samples (Culmer et al., 2009). Importantly, the three tasks that children complete on the CKAT (tracking, aiming and tracing) tap into different sensorimotor control processes. The tracking task involves following a moving dot with the stylus around a figure-8 type loop. This can be achieved in two ways – either through compensatory control, meaning that the child is continually aiming to reduce the error between the tip of their stylus and the centre of the moving dot (resulting in shorter, less smooth movements), or by predicting the motion of the dot and generate a smoother continuous movement. The aiming task requires the child to draw from one dot to another as quickly and as accurately as possible. This involves implementing fast feed-forward mechanisms and online corrections, whilst balancing the speed/accuracy trade-off, in order to reach the desired end-point location. Finally, the tracing task requires the child to draw along an abstract path, keeping in between the path boundaries. This involves both feedforward and feedback sensorimotor processes - accurate prospective control based on information about the future direction of the path, as well as continuous online corrections to reduce the steering error.

Therefore, in this study, the CKAT was used in a cross-sectional primary school population, in order to assess the relation between sensorimotor control skills and academic attainment in the main educational achievement indicators in primary school: mathematics, reading and writing (Department for Education, 2014).

4.2 Method

4.2.1 Participants

The CKAT task used for analysis in this study was taken as part of a school-wide motor and cognitive screening, which took place in a single primary school in the city of Bradford, UK. All children in the school were invited to take part in the larger study (n = 451), which aimed to provide the school with information about whether children might be in need of extra support in certain areas. Written informed consent was obtained from the head teacher on behalf of the school. As all the tests were administered in school time, the school then obtained informed consent from the parents or guardians of the children. Parents were given a full, written information sheet, which included contact details of the research team in order to enable them to ask any questions, or opt-out their child from the study (which they could do verbally or in writing). After verbally explaining the measurements to each child, they were also asked for verbal consent. Approval for the study (including the consent procedure) was given by the University of Leeds Ethics and Research committee (ref no. 14-0061), and this included a full risk assessment of all testing procedures.

Overall, consent was obtained for 449 children, in Reception (age 4-5) to year 6 (age 10-11). There were no exclusion criteria for participation in the measurements, but the inclusion criteria for being included in the analysis was that their academic attainment data on the standard scoring system was available. Therefore, the 56 children in Reception were not included, as they had not yet been assessed on this scale. Additionally, a group of twelve children with special educational needs, who were assessed on a different scale for attainment were excluded from analysis. This left a final sample of 381 (186 male) children in years 1-6, aged 5-11 (see Table 4.1 for demographics).

Table 4.1: Demographic information for final sample of participants, split by year of schooling

Year of school	n	Age		Gender
		mean	(sd.)	males:females
Year 1	52	6.05	(0.29)	30:22
Year 2	63	7.01	(0.28)	29:34
Year 3	57	8.07	(0.26)	26:31
Year 4	61	9.05	(0.32)	30:31
Year 5	88	10.10	(0.28)	39:49
Year 6	60	10.99	(0.30)	32:28
Total	**381**	**8.69**	**(0.51)**	**186:195**

4.2.2 Materials and procedure

Sensorimotor control was assessed using the Clinical Kinematic Assessment Tool (CKAT). The CKAT uses Kinelab software (see Culmer, Levesley, Mon-Williams, and Williams (2009) for full underlying architecture) and was run on a Toshiba Portégé tablet computer (screen size: 260 x 163 mm, 1280 x 800 pixels, 32 bit colour, 60 Hz refresh rate). A pen-shaped stylus was used as the input tool in order to measure kinematic responses to interactive stimuli presented on the screen. The battery consists of three tasks: tracking a moving dot (tracking), aiming between a series of stationary dots (aiming), and tracing along a series of abstract paths whilst trying to stay in-between the guide lines (tracing).

The CKAT was completed in the school library during the school day, where children were brought in small groups. The child was sat at a table with the tablet in a landscape orientation on the table directly in front of them. The researcher read out the instructions that appeared on the screen, and ensured the child understood the task. The total CKAT battery took between 15-20 minutes.

4.2.3 Outcome measures

4.2.3.1 Sensorimotor control

For the tracking task, root mean square error (RMSE) was calculated for each speed of the dot (slow, medium or fast), both with and without the guide line. The median RMSE for these six conditions was then calculated as the tracking outcome variable. The average movement time (MT) for the first 50 aiming movements (out of a total of 75) was calculated as the outcome variable for the aiming task, since the last 25 movements included some additional 'jump' trials, where the target moved before the child had reached it. Average path accuracy (PA) and path-length time (PLT) were extracted for each of the six tracing paths. A penalised path accuracy score (pPA) was then calculated for each path in order to adjust for the time taken, based on the 'ideal' 36 seconds that was prompted by the moving box during the task. The median pPA for each of the six tracing paths was calculated for the tracing outcome variable.

4.2.3.2 Academic attainment

Attainment scores for mathematics, reading and writing, on the UK nationally standardised scale (Department for Education, 2014) were obtained for each child from the school. This scale runs from 1 to 5, and within each of these levels, children are also assigned a letter (a, b or c; with a being the highest), with the lowest possible attainment score being 1c, and the highest 5a. Using this system, by the end of year two the level pupils are expected to reach is a 2b, and by the end of year 6, they are expected to achieve a 4b. For this study, these grades were converted to a fifteen point scale (with the lowest grade using the previous scale (1c) now being coded as 1, and the highest (5a) now coded as 15).

4.3 Results

There were missing data for each of the CKAT tasks, due either to participant absence or errors in data extraction. 16 children had data excluded due to either not understanding task instructions, switching hands during the tasks, or refusal to complete the tasks. One data point for the tracing task was excluded from the analysis due to a z score of 15.15.

Within the raw data, there was a large positive skew for the CKAT variables. In order to compensate for this, the CKAT variables (tracking, aiming and tracing) were reciprocally transformed. This ensured acceptable levels of skewness and kurtosis (see Table 4.2).

Table 4.2: Descriptive statistics before and after transformations for fine motor variables (tracking, aiming, tracing) and academic attainment (mathematics, reading and writing)

Outcome	Transformation	n	Mean (SD)	Minimum	Maximum	Skewness	Kurtosis
CKAT Tracking	None	362	16.82 (9.56)	6.47	62.83	2.23	5.39
CKAT Tracking	Reciprocal	362	0.07 (0.03)	0.02	0.15	0.11	-0.33
CKAT Aiming	None	361	1.55 (0.32)	1.02	2.98	1.26	2.54
CKAT Aiming	Reciprocal	361	0.67 (0.12)	0.34	0.99	-0.05	-0.31
CKAT Tracing	None	356	1.50 (0.50)	0.76	3.48	1.58	2.91
CKAT Tracing	Reciprocal	356	0.73 (0.20)	0.29	1.31	0.13	-0.24
Attainment - Mathematics	None	372	6.05 (2.82)	1.00	14.00	0.13	-0.59
Attainment – Reading	None	371	5.94 (3.16)	1.00	15.00	0.35	-0.37
Attainment - Writing	None	371	5.80 (2.78)	1.00	12.00	0.06	-0.81

Correlations between the variables were then examined, as well as correlation with year group (see Table 4.3). All variables correlated significantly with year group, indicating performance improved as the children grew older. There was an extremely high correlation between the three academic attainment scores (mathematics, reading and writing), $r > .93$. The CKAT variables all showed a medium-to-large correlation with the academic attainment variables, and with each other, r values .45 to .60, indicating that children who performed well on the CKAT also had better academic attainment scores.

Table 4.3: Correlations between year of schooling, academic attainment and fine motor variables

	Year group[1]	Maths[2]	Reading[2]	Writing[2]	CKAT Track[3]	CKAT Aim[3]	CKAT Trace[3]
Year group[1]	1.00						
Maths[2]	.79**	1.00					
Reading[2]	.76**	.93**	1.00				
Writing[2]	.80**	.94**	.95**	1.00			
CKAT Tracking[3]	.39**	.47**	.46**	.45**	1.00		
CKAT Aiming[3]	.59**	.60**	.58**	.59**	.55**	1.00	
CKAT Tracing[3]	.49**	.58**	.59**	.59**	.45**	.51**	1.00

[1] Year groups from 1-6, [2] Attainment scores mapped from government levels to 15 point scale (higher score = better performance), [3] CKAT variables reciprocally transformed (higher score = better performance)
***p < .05, **p < .01**

A number or regression analyses were then run, in order to examine whether sensorimotor performance would explain any of the variance in academic attainment scores. Mathematics, reading, and writing scores were the outcome variables in each analysis. Because the year group the child was in significantly correlated with all the variables, year group was added in as the first step in each model.

Age explained around 60-70% of the variance in mathematics, reading and writing attainment scores. When the sensorimotor variables were entered into the model, they explained an extra 6% of the variance in mathematics scores, 7% of the variance in reading scores, and 5% of the variance in writing scores (see Table 4.4). Looking at the individual sensorimotor variables, the tracing task contributed significantly to all three models predicting mathematics, reading and writing attainment scores. Tracking added significantly to the mathematics and reading attainment models, but not to the model for writing attainment. The aiming task did not contribute significantly to any of the models.

Table 4.4: Stepwise multiple regression models for motor performance predicting academic attainment

Outcome	Model	Predictors	R^2 *Δ*	B	Std. Error B	*β*
Mathematics	Step 1: Year group	Constant	.65**	-5.43	0.47	-
		Year Group		1.33	0.05	.81**
	Step 2: Year Group	Constant	.06**	-6.68	0.50	-
	+ Sensorimotor	Year Group		1.05	0.06	.64**
		Tracking		9.63	3.65	.09**
		Aiming		1.66	0.93	.07
		Tracing		2.56	0.51	.18**
Reading	Step 1: Year Group	Constant	.60**	-6.53	0.57	-
		Year Group		1.45	0.06	.77**
	Step 2: Year Group	Constant	.07**	-7.89	0.61	-
	+ Sensorimotor	Year Group		1.12	0.08	.60**
		Tracking		10.80	4.40	.09*
		Aiming		1.15	1.13	.04
		Tracing		3.67	0.61	.23**
Writing	Step 1: Year Group	Constant	.67**	-5.71	0.45	-
		Year Group		1.33	0.05	.82**
	Step 2: Year Group	Constant	.05**	-6.76	0.49	-
	+ Sensorimotor	Year Group		1.08	0.06	.66**
		Tracking		6.74	3.55	.07
		Aiming		0.90	0.91	.04
		Tracing		2.97	0.49	.21**

* $p < .05$, ** $p < .01$

4.4 Discussion

This study aimed to use an objective measure of motor control that could reliably differentiate between children on the basis of specific sensorimotor control abilities, and examine the relation between these sensorimotor control abilities and academic attainment outcomes (mathematics, reading and writing) in the primary school population.

It was found that across the whole-school sample, overall ability on the CKAT was significantly related to mathematics, reading, and writing attainment scores, consistent with previous work that had examined this relation in longitudinal studies (Grissmer et al., 2010; Luo et al., 2007) and cross-sectional studies (Sortor & Kulp, 2003). However, the use of an objective measure, scored on a continuous scale, allowed motor ability to be examined as a dimensional construct in a reliable way for the first time.

All the tasks on the CKAT involved 'pen-skills' – i.e. using a stylus to interact with visual stimulus, and the significant effects found here are in agreement with the study by Dinehart and Manfra (2013) who found comparable results with their fine motor copying task. Considering nearly all academic assessment involves using a pen to write down knowledge and ideas, this might explain why children who find the motor aspect of using a pen difficult would likely suffer in their academic work. For example, Visser (2003) put forward a case for an 'Automatization Deficit' being key in the negative outcomes associated with poor movement control. This hypothesis states that if a task involves two components and the first skill is not automatised, then adding a secondary task will results in a breakdown in performance. So, in the case of a written examination, adding in the motor demands of writing will result in a division of cognitive effort between physically writing and recalling information relevant to the test, leading to a lower grade for children with poorer pen-skill control. Similarly, it has been suggested that for children with difficulties controlling a pen, the demands of these motor requirements during writing means they have fewer cognitive resources for text composition (Medwell et al., 2009).

However, CKAT also allowed the exploration a number of specific sensorimotor control skills separately. It was found that, rather than all these control skills being related to all the academic attainment outcomes, each showed differing relations. The tracing task was a significant predictor for mathematics, reading and writing, the tracking task significantly predicted mathematics and reading attainment scores (although there was a much weaker relation than with tracing) whereas the aiming task was not significantly related to any of the attainment outcomes.

There are a few reasons as to why this might be the case. Firstly, it is argued that motor development is crucial for 'learning to learn' (Adolph, 2008). The neural infrastructure developed during learning to move in variable and novel situations, as opposed to merely responding to cues, is also used for other high-level cognitive functions such as self-regulation and working memory. If capacity for certain high-level cognitive functions is linked to some sensorimotor tasks more than others, this would explain why each of the CKAT tasks, tapping into different sensorimotor control skills, had differing relations. More specifically, it may be that developing the neural infrastructure for the sensorimotor control skills involved in the tracing task (feedforward prospective steering control, and continuous online corrections), is particularly useful for learning other higher-cognitive skills. In comparison, the requirements of the aiming task (extremely fast feed-forward mechanisms) may not those required for these higher-level functions. Tracking meanwhile, showed a relation with mathematics and reading, but not writing (and to a much smaller extent than tracing). Again it may be that the cognitive functions required for the writing assessments may not be 'trained' when practicing tracking type movements, whereas those required for mathematics and reading are.

A complementary theory is that the same aetiological neural pathways may be responsible for both certain sensorimotor processes and higher cognitive processes such as language and working memory, and it is therefore dysfunctions in these pathways that result in a range of motor and cognitive difficulties. Indeed, Diamond (2000) summed up evidence from neuroimaging and neuropsychological patient studies that show the importance of the cerebellum and prefrontal cortex for both cognitive and motor tasks.

The cerebellum has indeed been found to be involved in steering behaviour (Field, Wilkie, & Wann, 2007; Ramnani, 2006), comparable to the tracing task on the CKAT (Raw, Kountouriotis, Mon-Williams, & Wilkie, 2012), and this may explain why performance on this task was particularly linked to the attainment outcomes.

Likewise, language processing circuits have been shown to be reciprocally connected with motor systems (Pulvermüller & Fadiga, 2010), and again deficits in these pathways would result in difficulties with both motor and language function (Iverson, 2010). In particular, the executive functioning hypothesis suggests that motor difficulties are indicative of a dysfunction of the cerebellum, which through the striatal pathways would lead to problems in the prefrontal cortex, and through this, would result in a deficit in executive function (Diamond, 2000; Vuijk, Hartman, Mombarg, Scherder, & Visscher, 2011). Again, this would explain the strong link with the tracing task, where the sensorimotor control requirements of the task may also utilise these areas. Providing supporting evidence for this, Roebers et al. (2014) showed that the relation between fine motor function and academic outcomes disappeared when executive function was included in the model. In order to investigate this further, it would be necessary to take measures of these other cognitive functions alongside measurements of sensorimotor control, and examine the specific contributions of each to academic outcomes. Clearly, there are also other sensorimotor control processes (for example, performing sequences of movements) that were not measured in this study. Building up an understanding of these complex interactions however, using objective measures that will reliably differentiate nuances in performance, is crucial for identifying the pathways for intervention to ensure that all children succeed in their academic life.

The results presented in this study have provided definitive evidence that motor function (i.e. sensorimotor control processing) is linked to academic attainment in the general population, by addressing the issues with measuring motor performance inherent in much of the previous literature. In addition, evidence was found that *specific* sensorimotor control skills are central within this relation. Therefore, targeting these specific processes may be an effective means to intervention in children of primary school age.

CHAPTER 5

ROBOT GUIDED 'PEN SKILL' TRAINING IN CHILDREN WITH MOTOR DIFFICULTIES

5.1 Introduction

In Chapter 4, it was shown that the motor functions required to use a pen are related to academic achievement at primary school. In particular, that the sensorimotor skills that are involved in tracing may be particularly influential. There is good evidence that the negative outcomes associated with poor motor performance can be minimised if identified early enough and treated with appropriate intervention (Niemeijer, Smits-Engelsman, & Schoemaker, 2007; Sangster, Beninger, Polatajko, & Mandich, 2005; Smits-Engelsman et al., 2013), yet there is currently no clear agreement on the most effective method for intervention (Blank et al., 2012). The results from the experiment in Chapter 4 would suggest that training certain sensorimotor skills – accurate prospective control and online corrections, may be an effective route for children to improve their academic attainment.

One intervention strategy that is showing increasing promise in the field of rehabilitation medicine is the use of robotic systems to support sensorimotor learning (Nowak, Glasauer, & Hermsdörfer, 2013; Wolpert, Diedrichsen, & Flanagan, 2011). Robotic devices can constrain the 'action space' that needs to be explored by a user when learning a movement pattern (Holt et al., 2013; Kwakkel, Kollen, & Krebs, 2007; Lo et al., 2010; Reinkensmeyer & Patton, 2009; Williams & Carnahan, 2014). This can allow actions to be more accurate from the start, enabling the creation of appropriate internal models, which can be refined more effectively using tailored assistive forces (e.g. increasing resistance when the user moves away from a defined spatial path). Whilst too much assistance may actually hinder learning of movements for healthy individuals, for individuals with disabilities or difficulties with movement, these systems do show potential (Holt et al., 2013; Kwakkel et al., 2007; Lo et al., 2010; Reinkensmeyer & Patton, 2009; Williams & Carnahan, 2014). Moreover, robotic interventions have a number of advantages over traditional approaches. The ‘dosage’ of the intervention can be strictly controlled, meaning each child can receive the same therapeutic experience, a single supervisor can provide guided treatment to a group of children at once, rather than on a one-to-one basis, and therapy can be embedded within computer games that children enjoy, find motivating and are non-stigmatising (with potential concurrent benefits of improved self-efficacy).

On this basis, a robotic intervention system for training pen-skills was designed with the potential to be used within a school or home environment without the need for one-to-one administration (Snapp-Childs, Flatters, Fath, Mon-Williams, & Bingham, 2014; Snapp-Childs, Mon-Williams, & Bingham, 2013). Users interfaced with the system by grasping a stylus attached to a haptic robotic arm and moved the arm to complete a series of trials within a ‘computer game’ that required them to perform tracing tasks, by moving the stylus along a 3D path. The robotic arm assisted the user in making the correct movements (by providing resistive forces when the stylus left a defined path), whilst still requiring active prospective control from the participants. This type of control, rather than passive guidance, has been found to be necessary for effective learning (Snapp-Childs, Casserly, Mon-Williams, & Bingham, 2013).

Initial studies investigating the feasibility of using this system have shown that training can ameliorate differences in performance between children (7-8 years old) with and without clinical movement difficulties (Snapp-Childs, Mon-Williams, et al., 2013), of different ages (Snapp-Childs et al., 2015), and between children dichotomously classified as either ’high’ or ‘low’ for their score on the Beery-Buktenica Test of Visual-Motor Integration (Beery, Buktenica, & Beery, 1997) visual perception (VP) test (Snapp-Childs et al., 2014). Moreover, there was some evidence for generalisation of the robotic system in the study of children with differing VP status (i.e. training benefits accruing on a different task). Children in both groups were found to have performed better on a digital tablet-based drawing task post-haptic training. This raises the possibility that the system could be used to target a critical daily activity for children within schools – pen skills, which was shown in Chapter 4 to relate to academic performance. There is an urgent need for cost-effective solutions to supporting children with handwriting difficulties within schools so this is an exciting possibility.

The current study therefore set out to investigate the generalisability of training benefits to the ‘pen-skills’ measure of fine motor function, namely the Clinical Kinematic Assessment Tool (CKAT) (Culmer et al., 2009). As well as the tracing task being shown to be particularly related to academic attainment, the sensorimotor control requirements tap into many of the skills required ‘real-life’ activities such as handwriting (for example, exerting precise forces on a stylus and making use of feedforward and feedback control). It therefore makes an ideal assessment to test whether training benefits are able to generalise to the sensorimotor control tasks that may influence many tasks crucial for academic success.

The present study utilised a counterbalanced crossover design that investigated haptic-training effects in children identified as having manual coordination difficulties. Consequently, for the first time, it is was possible to directly investigate whether: (i) post-training benefits on the novel robotic arm tasks were directly attributable to the training rather than being a function of natural improvement due to practice effects or baseline ability; (ii) there was evidence of generalisation of the benefits on the CKAT battery of sensorimotor control; (iii) any benefits observed in performance were sustained even after training was withdrawn.

5.2 Method

5.2.1 Participants

The children involved in this study had previously taken part in the experiment reported in Chapter 2. From the 470 children on the school roll for 2013, the class teachers had put forward those children they believed had ‘handwriting difficulties’ (n = 101), which represented 21% of the whole school. These children subsequently were tested using the Movement Assessment Battery for Children (MABC) 2nd Edition (Henderson et al., 2007), the most commonly used standardised test of motor ability in Europe (Blank et al., 2012). Fifty nine of these children (12.5% of the school population) scored under the 15th percentile on the manual dexterity section, and these children were selected for the intervention reported here. Therefore, these children could be said to have participation and activity level deficits.

Informed written consent was obtained from the Head-teacher of the participating school (acting in loco parentis for their students). The school also obtained informed consent internally from the parents/guardians of children selected, giving them advanced notice of the study and their right to opt out should they wish to do so. Written information detailing the study was sent out to all families and they were given the opportunity to discuss the study verbally with informed staff members and the research team if they had further questions. Parents/guardians wishing to withdraw (opt-out) were able to do so either verbally or in writing (both recorded by an in-school coordinator). These multiple response methods and the embedding of this process in school, with the support of trusted staff-members, ensured that all parents/guardians were engaged with the consent process and that they had multiple modes by which they could let their wishes be known. Ultimately, consent to take part in the study was obtained for 51 of these children (Table 5.1). Children gave their verbal consent immediately prior to their participation in each phase of the study (i.e. consented for screening and then again for participating in the trial) after having the study explained to them, (since not all children in this age range could provide written consent). The University of Leeds Ethics and Research committee approved these consent procedures and all other aspects of the study's design and methodology (ref: 13-0112).

Table 5.1 Descriptive statistics of sample, split by counterbalanced group

		Age (in years)	Gender		Handedness		MABC-2 MD (%ile)	MABC-2 MD <5th percentile
Counterbalance Group	***n***	***Mean (Range)***	***Male***	***Female***	***Right***	***Left***	***M (SD)***	***n***
A	26	8.15 (5.10 – 10.96)	20	6	23	3	5.46 (3.31)	16
B	25	8.29 (5.29– 10.92)	14	11	24	1	4.58 (3.77)	16
Total	51	8.22 (5.10 – 10.96)	34	17	47	4	5.03 (3.53)	32

For whole sample, and split by counterbalanced group: age at initial baseline testing, gender, handedness, score on Movement Assessment Battery for Children(Second Edition) manual dexterity subsection (MABC-2 MD), and number of children scoring under 5th percentile on MABC-2 MD subsection.
A = Counterbalance group receiving Haptic-Training in time period 1 but not 2; B = Counterbalance group receiving Haptic-Training in time period 2 but not 1

5.2.2 Materials

5.2.2.1 Haptic-Training

The robotic system used in this experiment was the same as that used in previous studies (Snapp-Childs, Casserly, et al., 2013; Snapp-Childs et al., 2014; Snapp-Childs, Mon-Williams, et al., 2013), and consisted of a stylus attached to a haptic device; the PHANTOM Omni (Sensable Technologies, Inc.). The PHANTOM is an impedance control device which outputs a force in reaction to the user moving the input device (stylus) and interacting with a virtual 3-D path displayed on a computer screen (as a 2.5D image – i.e. with pictorial cues providing an impression of depth). The force used for this intervention was modelled as a virtual spring, which pulled the stylus back onto the nearest point on the correct spatial path when participants showed spatial deviation. The stiffness of the spring could be altered in order to adjust task difficulty, with the force set at six different levels of difficulty corresponding to forces of 2.02N, 1.08N, 0.83N, 0.57N, 0.35N and 0.13N. The virtual spring length was set at 0.5cm from the centre of the movement path. If the stylus was located within this threshold distance there were no forces applied. This did not involve any actively applied forces (as it was an impedance rather than admittance controlled device), and there were therefore, no safety concerns to the children.

The trials presented during haptic-training were the same as those used in previous studies and involved using the stylus to push a fish icon around a 3-D movement path shaped like a three-dimensional knot (Figure 5.1a). Participants began at a fixed starting location and moved their icon to a finishing location, whilst racing against computer-controlled ‘competitor’ fish presented on a 15 inch diameter laptop screen (Figure 5.1b). The paths themselves varied in length, curvature and torsion. At the beginning of a training session all children were given two practice trials, consisting of a circle and a loop, in order to familiarise them with the task requirements. After this practice, all the children were able to complete the paths on the highest (easiest) level of assistance (i.e. greatest stiffness).

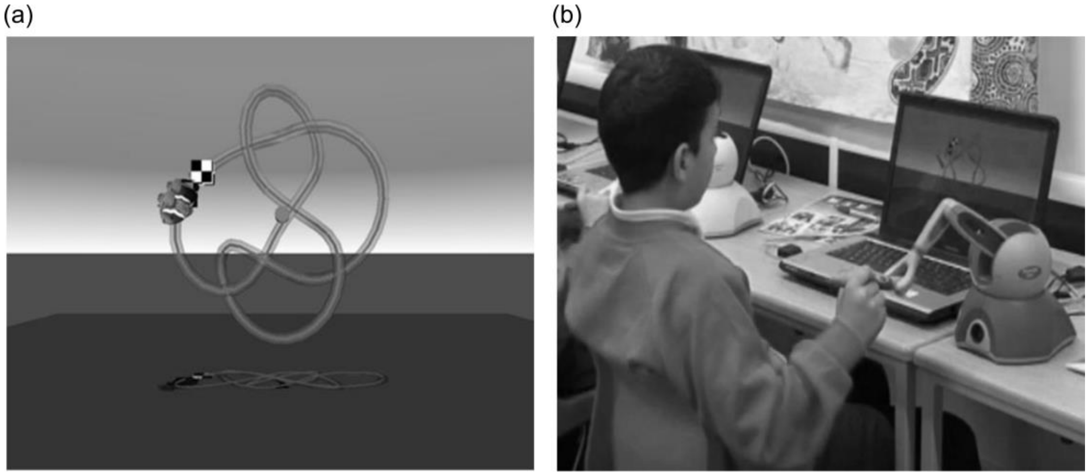

Figure 5.1 Set-up of the robotic arm system. The child traces around a 3-D path (a) represented on the laptop screen, using the pen attached to the robotic device (b)

For training purposes six blocks of trials were created, one to correspond with each of the stiffness levels that participants were trained on (i.e. haptic-assistance across all trials within a block was constant). Within all blocks the same sequence of trials was presented, which comprised of training on five unique paths (numbered 1 to 5) always presented consecutively in the same fixed order and with the complexity of the path increasing from Path 1 to Path 5. Within a block, task difficulty between trials was further manipulated by altering the speed of the competitor fish, with it taking 25 seconds to complete the path in a slow condition trial (starting when the child successfully placed the stylus on the 'start' square), and 15 seconds in a fast condition trial. Children started on the 'slow' condition on Path 1 and had to 'beat the competitor fish' twice in a row (with a maximum of six attempts). They then completed the same path in the 'fast' condition. Once they had completed these trials, they progressed to the 'slow' condition on Path 2 and so on. A full block constituted completing all five paths at both race speeds (Figure 5.2). In order to reduce frustration, if the child did not complete a path in 90 seconds after they first reached the start square, the trial was terminated.

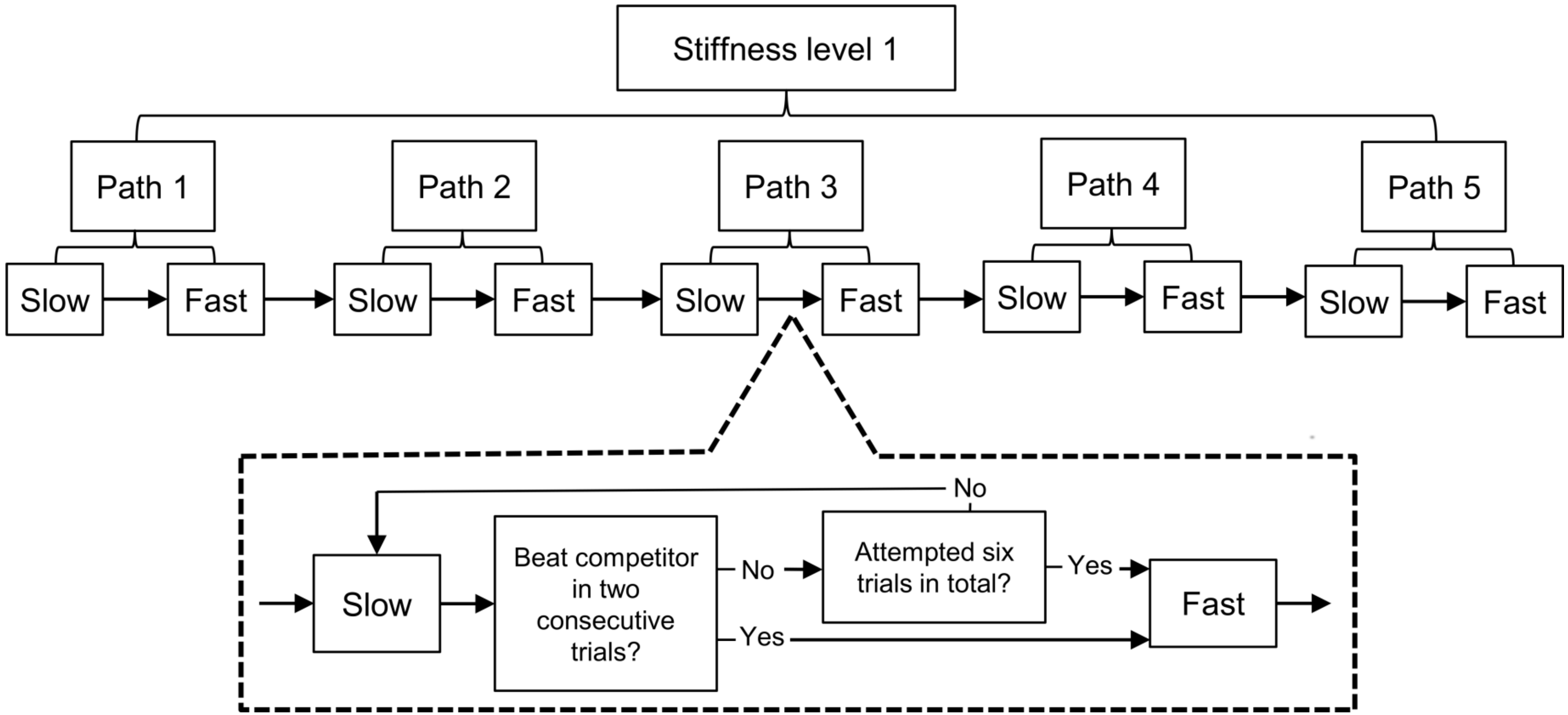

Figure 5.2 Schematic of training blocks. Child progresses through slow, then fast conditions for each of the five paths in a training block. Once completed, stiffness level is reduced for the next block.

5.2.2.2 Outcome measures

Participants completed the following battery of assessments before and after haptic-training and a control period:

5.2.2.2.1 Novel Haptic-System Trials

Using the same haptic system as deployed during training (i.e. Figure 5.1) participants were tested on a single novel path (not presented during training) across twelve consecutive trials. This sequence of trials started at the highest assistance level for two trials then proceeded through a further pair of trials at each assistance level in descending order. If the participant did not complete a trial in 90 seconds after they first reached the start square, the trial was terminated and they proceeded automatically to the next one in the sequence. If children failed to complete a trial then a maximum score of 90 seconds was awarded instead. The outcome variable for these trials was the median time (in seconds) to complete the paths. Other measures such as path length that were recorded were previously found to merely reflect this variable (Snapp-Childs, Mon-Williams, et al., 2013), and so they were not used as an outcome measure in this study.

5.2.2.2.2 Clinical Kinematic Assessment Tool (CKAT)

The primary outcome measure for this study was the objective measurement of pen skills. In order to assess pen skills, participants were tested on the Clinical Kinematic Assessment Tool (CKAT) (Culmer et al., 2009; Flatters, Hill, et al., 2014). The CKAT test battery consisted of three tasks (tracking a moving dot, aiming between a series of dots and tracing along a path), all performed with a 'pen' stylus on a tablet computer. The CKAT collects a large number of kinematic variables. However, for this study, only one outcome measure for each task was investigated as these measures have previously been shown to be sensitive to manipulations in task-difficulty, age and gender in 4 to 11 year olds (Flatters, Hill, et al., 2014). For the tracking task, average root mean square error was calculated as the straight-line distance (in mm) between the centre of the target and the tip of the stylus at each sampled time point. For the aiming task, movement time (MT) was calculated by taking the median MT for each of the aiming movements. For the tracing task, a penalised path accuracy score was calculated, by inflating path accuracy (the mean distance away from an idealised reference path in mm) by the percentage deviation from the optimal movement time of thirty-six seconds, to give a composite measure of performance reflecting both the speed and accuracy demands of this specific task. These were the same outcome measures as used in Chapters 2, 3 and 4.

5.2.3 Procedure

A crossover design was used in this study, with children being split into two groups (A and B), with allocation counterbalanced for age (see Table 5.1 for descriptive statistics of participants). Two time periods of 5-weeks were split by a 3-week gap (due to school holidays). Participants were assessed at the beginning and end of each time period on the battery of outcome measures already described. Group A received haptic-training during the first time period whilst Group B received no intervention. Group B then received the intervention in the second time period, whilst Group A received no intervention. This allowed the natural improvement of the children over time on the outcome measures to be taken into account when investigating additional, training specific, effects.

The intervention followed exactly the same procedure as that used in previous studies assessing the system (Snapp-Childs, Casserly, et al., 2013; Snapp-Childs, Mon-Williams, et al., 2013; Snapp-Childs et al., 2015, 2014). During the intervention period in which participants received haptic training, participants took part in one 20 minute long session per week. Children were brought out of class in groups of five to sit in a quiet, otherwise unused classroom, under the supervision of two researchers. The robotic arm systems were set up on tables next to each other, at height-appropriate tables. The laptop screen was set up directly in front of them, with the robotic arm placed on the right of the computer (or the left for the left-handed children). The children were allowed to progress at their own rate through the training blocks, which were delivered in a sequential order starting with the block providing the greatest assistance (i.e. highest stiffness). After each session, if they had progressed more than halfway through the current training block, they would start the next session at the beginning of the next block. If not, they started on the same block again.

5.2.4 Analysis

The two primary independent variables under investigation in this study were: participant's counterbalance group (A or B), and time of assessment (baseline or post-test at intervention period 1 or 2). Due to the skewness and kurtosis of the outcome measure scores for the Robotic Arm novel task and the CKAT tasks, the outcome measures were reciprocally transformed, enabling parametric tests to be used. Dependent variables for each task were analysed separately using 2x4 mixed ANOVAs that specified counterbalance group as a between-subjects factor (Group A or Group B) and time of assessment as a within-subjects factor (baseline 1 (B1), post-test 1 (P1), baseline 2 (B2) or post-test 2 (P2)). Some exploratory analysis was then done, splitting the participants by age and manual coordination ability, in order to look in depth at any influence of these additional factors. Such analysis also allowed for more detailed consideration of the feasibility of using the intervention equipment with younger children than tested in previous studies (Snapp-Childs et al., 2014; Snapp-Childs, Mon-Williams, et al., 2013).

5.3 Results

All the children reported that they enjoyed taking part in the training and were able to complete the tasks, with only one child withdrawing from the study (due to leaving the country). There were some missing data due to recording errors; participants needed to have valid data at all four time points in order to be included in the analysis for each test. Table 5.2 gives descriptive statistics for each of the time points for intervention groups A and B, and total valid data for each test. There was an issue with extreme outliers within the data on the Robotic Arm, CKAT tracing and CKAT aiming tasks ($|z| > 2.5$), and so analyses were run with and without these cases included.

Table 5.2 Descriptive statistics of outcome measures at each time point split by intervention group

Outcome	Group	Total valid n	B1 Mean(range)	P1 Mean(range)	B2 Mean(range)	P2 Mean(range)
Robotic Arm[1]	A	20	32.66 (10.31 - 80.01)	9.63 (6.32 - 17.43)	8.39 (4.82 - 15.38)	7.89 (5.80 - 11.00)
	B	21	35.15 (17.28 - 71.07)	26.70 (10.23 - 84.41)	16.04 (9.47 - 34.03)	8.20 (4.94 - 19.03)
CKAT: Tracking[2]	A	24	15.06 (8.34 - 36.59)	13.70 (8.77 - 27.80)	13.32 (7.57 - 26.30)	14.17 (8.36 - 32.65)
	B	21	17.26 (9.09 - 51.19)	17.48 (9.40 - 43.76)	17.01 (8.45 - 66.74)	18.71 (8.69 - 40.66)
CKAT: Aiming[3]	A	13	1.70 (1.15 - 2.64)	1.65 (1.20 - 2.13)	1.52 (1.07 - 2.30)	1.62 (1.11 - 2.26)
	B	10	1.59 (1.10 - 2.04)	1.55 (1.23 - 2.18)	1.43 (1.17 - 2.47)	1.44 (1.20 - 1.78)
CKAT: Tracing[4]	A	23	1.58 (0.87 - 2.63)	1.46 (1.02 - 2.48)	1.42 (1.06 - 1.96)	1.40 (0.86 - 2.25)
	B	24	1.79 (1.09 - 5.62)	1.58 (1.01 - 3.19)	1.84 (0.96 - 4.50)	1.63 (0.91 - 4.59)

B1 = Baseline 1; P1 = Post-test 1; B2 = Baseline 2; P2 = Post-test 2

[1] Robotic Arm scores: median time (in seconds) to navigate paths. [2] CKAT tracking measure: root mean square error [3] Aiming measure: average movement time [4]Tracing measure: penalised path accuracy

Scores shown are pre-transformation (therefore smaller scores indicate better performance on all tasks) and with all outliers included

5.3.1 Preliminary data exploration

Initial checks using independent t-tests were carried out to ensure that baseline scores on the outcome measures did not vary between the two intervention groups. Scores on the robotic arm novel task did not vary significantly $t\,(1, 47) = 1.30$, $p = .20$, and neither did scores on the CKAT tasks: tracking $t\,(1, 48) = .27$, $p = .79$; aiming $t\,(1, 40) = 0.11$, $p = .91$; and tracing $t\,(1, 49) = 0.43$, $p = .67$. In addition, there was no significant difference between groups regarding their performance on the MABC screening assessment $t\,(1, 49) = 0.90$, $p = .37$.

5.3.2 Robotic Arm novel task

Firstly, the impact of the intervention was examined on the novel task conducted on the robotic arm system. A mixed 2x 4 ANOVA was conducted, with intervention group as a between subjects factor (Group A (received intervention in Time 1) or Group B (received intervention in Time 2)), and time period entered as the within subject factor (baseline 1 (B1), post-test 1 (P1), baseline 2 (B2), post-test 2 (P2)). With the outliers included, there was a significant main effect of time F (3, 117) = 119.10, $p < .001$, $\eta p^2 = .75$ and group F (1, 39) = 33.79, $p < .001$, $\eta p^2 = .46$, as well as a significant interaction between time and group F (1, 117) = 20.50, $p < .001$, $\eta p^2 = .34$ (Figure 5.3).

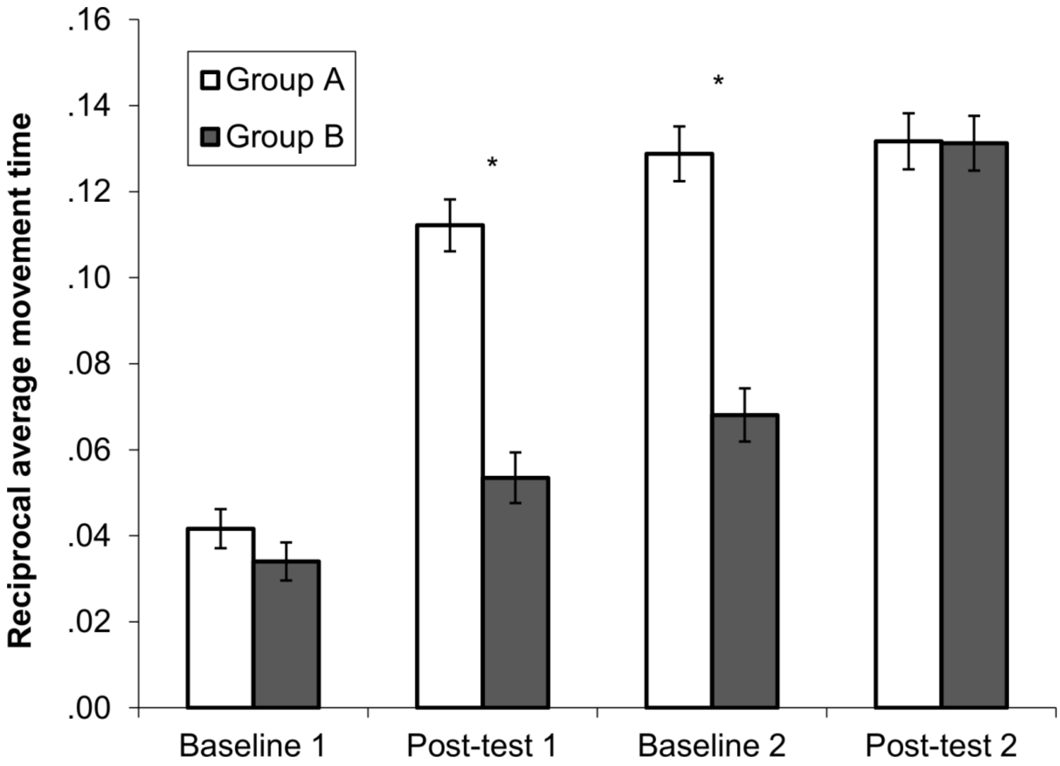

Figure 5.3 Task performance on novel robotic arm task

***$p < .05$, **$p < .001$ Reciprocal average time in seconds (therefore larger score = better performance) to complete all paths on novel robotic arm task (with standard error bars) for each group at each time point.**

Post-hoc tests using the Bonferroni correction revealed Group A improved significantly between B1 and P1 ($p < .001$). There was then a significant improvement between P1 and B2 ($p = .30$) or between B2 and P2 ($p = 1$), showing that their performance improved after the intervention. For Group B, they improved significantly between B1 and P1 ($p = .01$) and between P1 and B2 ($p = .03$). After receiving the intervention, there was again a significant improvement in scores between B2 and P2 ($p < .001$).

Looking at the differences between the two groups at each time point, there was no significant difference between the two groups at B1 t (47) = 1.30, $p = .20$, $r = .18$ After Group A received the intervention, at P1, there was now a significant difference between the two groups t (48) = 8.35, $p < .001$, $r = .77$. This significant difference was maintained after the three week gap at B2 t (44) = 7.09, $p < .001$, $r = .73$. Then at P2, after Group B received the intervention, there was no longer any significant difference between the two groups t (44) = .07, p = .95, r = .01. This shows that there was a boost in performance for each group after completing the intervention, on top of any natural development. No differences were found with the two outliers ($|z| > 2.5$) excluded from analyses.

5.3.3 CKAT battery

In order to examine whether there was any far transfer observed, the CKAT results were then analysed using the same structure.

For the tracking task (Figure 5.4a), there was no main effect of time F (3, 129) = .95, p = .42, ηp^2 = .02, no main effect of group F (1, 43) = 2.16, p = .15, ηp^2 = .05, or any interaction between time and group F (3,129) = .72, p = .54, ηp^2 = .02, indicating that there was no overall improvement with or without the intervention on this specific task. This pattern of results was replicated with the two outliers for tracking removed.

For the aiming task (Figure 5.4b), there was a significant main effect of time F (3, 63) = 2.96, p =.04, ηp^2 = .12, but no significant main effect of group F (1, 21) = .67, p = .42, ηp^2 = .02, or interaction F (3, 63) = .40, p = .76, ηp^2 = .02. However, using the Bonferroni correction, there were no significant differences between any of the time points when all of the children were grouped together and the main effect of time disappeared altogether when the three outliers were removed, indicating that there was no reliable improvement on the aiming task, with or without the intervention.

For the tracing task (Figure 5.4c), there was a significant main effect of time F (3, 135) = 2.86, p = .04, ηp^2 = .06, but no significant main effect of group F (1, 45) = .82, p = .37, ηp^2 = .02, or interaction F (3, 135) = .49, p =.69, ηp^2 = .01. There were no significant differences between any of the time points when splitting the children by group (all p > .20), but as a whole sample, there were significant improvements between baseline 1 and post-test 1 (p =.03) and between baseline 1 and post-test 2 (p = .05), indicating that there was a general improvement over time on this task, irrespective of when the intervention was completed. There were no outliers for this task.

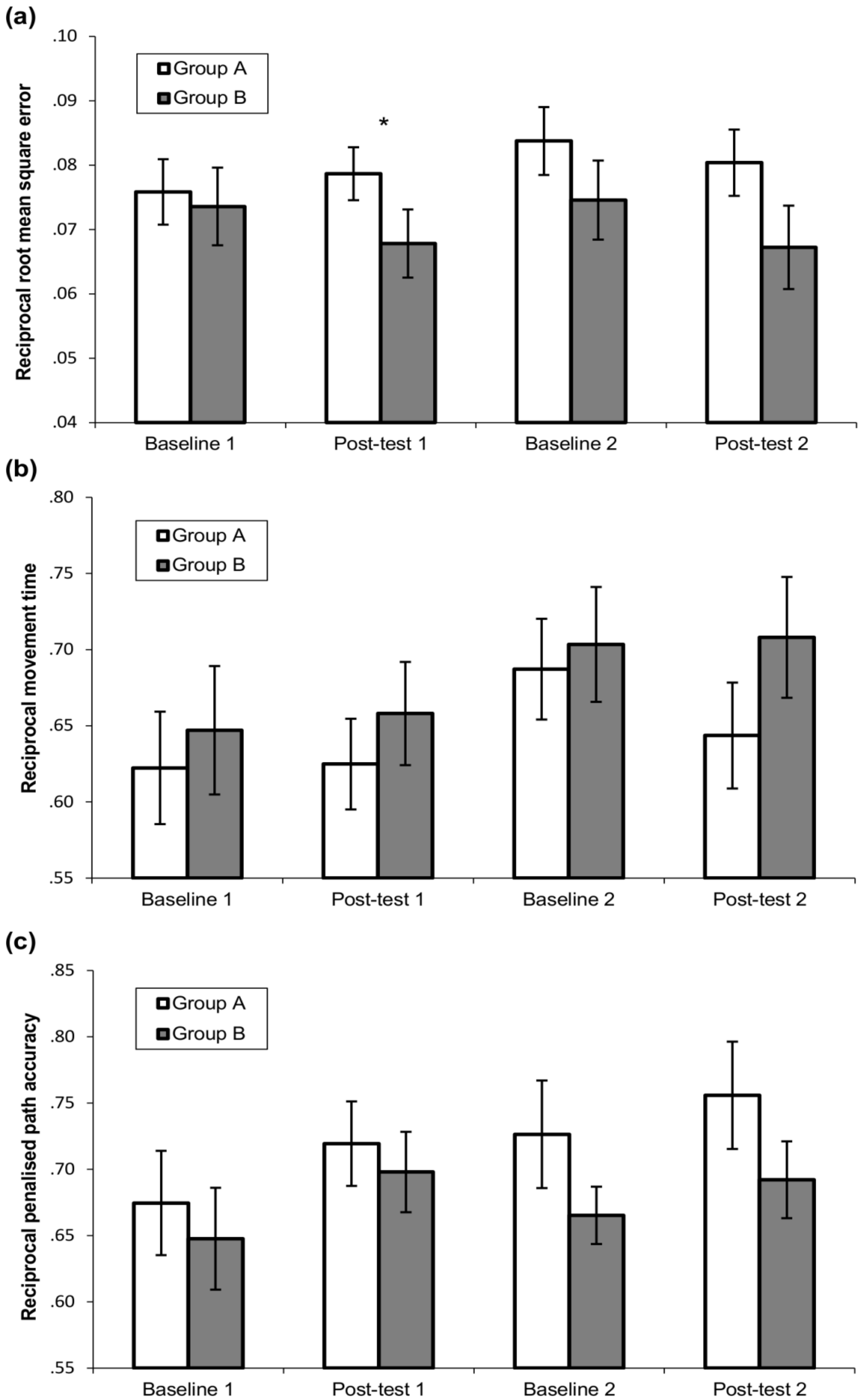

Figure 5.4 Performance on CKAT (a) tracking, (b) aiming and (c) tracing tasks

*$p < .05$, **$p < .001$. Reciprocal scores (therefore higher score = better performance) with standard error for CKAT variables: (a) tracking (root mean square error) (b) aiming (movement time) (c) tracing (penalised path accuracy)

5.3.4 Exploratory analysis and age feasibility

Previous work with this system has only used children over the age of 7 years, whereas children as young as 5 years were used in this study. The data were therefore split by school year into two groups: 5-7 years and 8-12 years. The same pattern or results for learning on the robotic arm was observed, with significant main effects and a significant interaction for both groups. The same pattern was also observed for the CKAT tasks, indicating that no particular age-group responded differently to the intervention.

Whilst all the children who took part in this study were classified as having manual coordination impairments by scoring under the 15th percentile on the MABC, the MABC handbook suggests a score of under the 5th percentile on the MABC-2 (Henderson et al., 2007) should be used as a diagnostic threshold for Developmental Coordination Disorder, with those under the 15th percentile (the threshold used in the current study) classed more broadly as being ‘at risk’. In addition, those children scoring ‘high’ or ‘low’ on the Beery Visual Perception task in a previous study (Snapp-Childs et al., 2014) showed differing levels of improvement on the drawing task used in the study. Therefore, it was hypothesised that the intervention may have more or less of an effect depending on the initial level of severity of motor difficulties. The children were therefore split into two groups: those scoring under the 5th percentile and those scoring over the 5th percentile. No difference again was found for the pattern of results on the robotic arm novel task or the CKAT tasks.

5.4 Discussion

This study aimed to examine, using a counterbalanced-crossover design, whether the training benefits of an intervention delivered using a robotic-arm system would generalise to improvement on an objective assessment of manual coordination. It was first confirmed through the use of a counterbalanced, crossover design that increases in performance on the novel task using the robotic arm system were directly attributable to the intervention, something that was not possible in previous studies examining this robotic system (Snapp-Childs, Casserly, et al., 2013; Snapp-Childs, Mon-Williams, et al., 2013; Snapp-Childs et al., 2015, 2014). Group A (who completed the intervention in the first time period) showed significantly more improvement at the first post-test than Group B, who undertook no additional manual coordination training during this time. In addition, the crossover design showed that the improvement was maintained almost two months after the intervention was withdrawn. Some improvement was also observed in Group B over this first time period (before they took part in the intervention); this could be attributable to either natural development over time, or the fact that even performing the baseline and post-test using the equipment may have constituted 'training'. However, the large difference in performance between the two groups was only eliminated after Group B had also completed the intervention in the second time period.

Secondly, the aim was to examine whether there was any evidence of the benefits generalising to the CKAT – an objective, computerised measure of motor 'pen-skills' that taps into specific sensorimotor functions. No evidence of improvement directly attributable to the intervention was found, with only the tracing task on the CKAT showing any improvement between time-points. It is always difficult to interpret a null-effect, and part of the difficulty in establishing an effect may be due to the huge amount of variability in the data (consistent with the fact that all of these children had motor problems at the activity and participation levels), which in a small sample may have masked any group-level effects. However, the current findings argue for increased caution when considering whether the intervention, as it currently stands, can be used to improve manual coordination generally.

The initial hope was that if the intervention could be shown to improve specific sensorimotor control processes, this might enable benefits to be extrapolated to a number of related tasks (for example, handwriting). Snapp-Childs et al. (2014) had found some evidence of transfer to a drawing task, although this was with a smaller sample of 28 children, only four of which were shown to have motor difficulties before the training. However, if there had been evidence of generalisation to the CKAT using the more robust cross-over study design (particularly the tracing task), it would give strong support for the use of this system as an intervention to improve 'real-life' tasks and potentially academic attainment. It may be the case that it was some aspect of the CKAT tasks themselves which prevented generalisability of the training benefits being seen; whilst the CKAT tasks and the robotic intervention all involved 'pen-skills' (defined as the ability to apply the appropriate forces to a handheld stylus so that a given visual output is achieved, the sensorimotor control processes involved in the robotic intervention tasks may in fact be different to those required for the CKAT tasks. The tracing task was arguably the most similar to the robotic arm task, and was the skill that was hoped to be targeted given the links with educational attainment shown in Chapter 4. However, the only way to progress on the robotic arm task was to move along the correct path, and therefore the children aimed to perform the movement as quickly as possible. In contrast, the guide box of the tracing task encouraged a fixed speed of movement, and so the accuracy of the movement was key.

Alternatively, it may be that it is not possible to train specific sensorimotor skills. Therefore, rather than trying to improve underlying motor deficits, it is instead more useful to target specific skills at the activity level, and allowing for the fact that every 'real-life' skill involves other cognitive processes. In which case, the actual tasks performed during the intervention would need to be tailored to target specific skills such as handwriting. The robotic arm training involved moving in 3-D which meant that movements involved the whole arm, as opposed to normal pen movement which involves mainly the wrist. There is evidence that learning similar skills with different effectors produces interference in generalisation (Krakauer, Mazzoni, Ghazizadeh, Ravindran, & Shadmehr, 2006), and therefore the training may also need to take place on a 2-D, horizontal plane. Likewise, the specific movement patterns involved in handwriting might need to be targeted for optimal intervention – for example, combining the type of repetitive letter writing used by Palsbo with their passive robotic system (Palsbo & Hood-Szivek, 2012) with the active support and feedback of the current robotic device.

The analysis did enable us to obtain evidence for the feasibility of using this type of system with a wider age range of participants than used in previous studies. An almost identical pattern of results on the novel robotic task was obtained for the children at all age bands and, most importantly, the training benefits on the robotic arm could be seen even in those aged as young as 5 years, which is ideal due to the emphasis on developing manual coordination skills such as handwriting at this age (Dinehart, 2015; Medwell & Wray, 2008). The system was readily deployed within the school environment, with the system (and outcome) being regarded positively by teachers and children. It should be emphasised that the current study used researchers to supervise the intervention but there were no obvious reasons why teaching staff could not have undertaken this responsibility (and might even be better in this role given their experience of working with children from an educational perspective). However, a greater evidence base of benefit would be required before the system could be recommended to schools as a feasible method of improving manual skills. Currently, the training relied on the use of existing robotic devices reprogrammed to run the intervention games, and therefore would be too expensive for mass distribution to schools. However, if the training regime could be altered to show benefits with these children, then it would be possible to develop cheaper devices. It is worth noting that even the current price of these robotic systems makes delivery of this intervention (with multiple children receiving therapy at the same time) potentially far more cost effective than providing one-to-one specialised help.

In conclusion, this experiment has shown, using a strong methodological design, that the robotic arm system is effective at training manual skills in a wide age range of children with motor difficulties. However, no generalisation of benefit was found to a specific set of computerised pen-skill tasks, indicating that it may be necessary for robotic systems to target task-specific actions in order to improve specific manual skills (such as handwriting).

CHAPTER 6

ASSESSMENT OF A SCHOOL-LED INTERVENTION FOR CHILDREN WITH HANDWRITING DIFFICULTIES

6.1 Introduction

It is a matter of common observation that children in primary school spend a lot of their time acquiring and deploying manual motor skills. The most notable example is found in the action of handwriting. Handwriting is an activity that is defined as the production of letters and words using a pen. It involves a number of underlying motor control processes such as being able to accurately apply forces to the pen in order to move it across the page. However, handwriting also involves other processes such as memory for letter shapes (Hayes, 1996; Medwell et al., 2009; Smits-Engelsman, Niemeijer, & van Galen, 2001). Thus, a deficit in one or more of these underpinning domains might reasonably be expected to result in poor handwriting output.

Handwriting is in itself, an important component of the language skill of writing – expressing ideas and thoughts in a written form (Medwell et al., 2009). Children that struggle with the mechanics of handwriting have been shown to have reduced cognitive capacity for other cognitive tasks such as generating creative ideas (Medwell et al., 2009). Similarly, when the cognitive load of a writing task is increased (e.g. by requiring creative input), then legibility of the handwriting is found to decrease, even amongst children without any handwriting difficulties (Graham, Struck, Santoro, & Berninger, 2006). It is no surprise therefore, that handwriting has been found to predict academic attainment even at an early age (Dinehart, 2015), and poor handwriting (usually characterised by a lack of legibility or speed) has been found to correlate with lower cognitive and literacy scores (McCarney, Peters, Jackson, Thomas, & Kirby, 2013). In a recent meta-analysis, it was shown that less legible pieces of educational work were scored more harshly than pieces of work with equivalent content that were more legible (Graham, Harris, & Herbert, 2011). It follows that the academic potential of children with poor handwriting will be hindered by difficulties with this ability.

The interaction between different motor control and cognitive processes in handwriting suggests that the problems experienced by children with motor problems will not disappear if writing is replaced with typing. The ability to grasp and manipulate a pen has clear implications for writing outcomes (Feder & Majnemer, 2007), but such fundamental problems are likely to also interfere with a child's ability to move their hands skilfully across a keyboard. Moreover, research has shown a synergistic relation between the process of writing letters and words and acquiring the related skills of spelling and reading. Evidence has shown that the process of actively writing letters facilitates a child's ability to remember and identify letters from memory (Longcamp et al., 2008; Longcamp, Zerbato-Poudou, & Velay, 2005). In support of this hypothesised role for writing in learning to read, it has been found that the ability to reproduce a previously shown shape (visual-motor memory) explains unique variance in attainment scores not only for writing but also for reading (Waterman et al., 2014), and in Chapter 4 it was shown that a fine-motor tracing task was related to academic attainment outcomes in mathematics, reading and writing. Therefore, it is important to help children overcome difficulties with handwriting rather than simply find ways to substitute this motor behaviour with others such as using a keyboard.

There is good evidence that providing one-on-one handwriting intervention can improve the quality, endurance and speed of children's writing (Santangelo & Graham, 2015). It has been claimed that over fifty percent of occupational therapists frequently provide one-to-one handwriting intervention sessions when possible (Feder, Majnemer, & Synnes, 2000). However, the fact that up to a third of children show some form of handwriting difficulty means it is simply not feasible to provide this kind of support for the majority of children. There is a need, therefore, to find novel ways of providing handwriting intervention to children with difficulties. In Chapter 5, a haptic robotic system was trialled that aimed to improve the underlying functional motor difficulties associated with pen skills. However, this was not found to be effective in transferring benefit to other pen skill tasks. Therefore, in this chapter, an alternative method of intervention is examined.

One tactic that is gaining increasing support within the literature is the idea of a graded approach to the delivery of services to children with difficulties (Camden et al., 2015; Stephenson & Chesson, 2008). This graded approach assumes that the first step in treating any difficulties should be the provision of intervention and support at the level of the school or home environment, with general intervention programmes that can be provided by non-specialists (i.e. parents or teachers) being made widely available (Camden et al., 2015). This would then mean that only those children who continue to struggle would need to be referred to specialist services for more individualised help (thereby reducing the pressures on services which are otherwise unable to meet demand). This approach is increasingly advocated for children with handwriting problems (Feder et al., 2000; Feder & Majnemer, 2007; Hoy, Egan, & Feder, 2011; Wallen, Duff, Goyen, & Froude, 2013). In particular, the need for an intervention that can be implemented by teaching staff and used in any classroom has been highlighted (Dinehart, 2015). Indeed, Sugden and Chambers (2003) and Wright and Sugden (1998) showed that interventions can be successfully implemented by teachers and parents in a population of children with specific clinical motor problems. However, these interventions still required one-to-one support from the teachers, and the teachers in one of the studies felt it was not easy to incorporate such a demand on their time amongst their other duties (Sugden & Chambers, 2003).

One way to substantially reduce the demand on an individual teacher would be to run the intervention in groups, particularly since there are often a number of children in each class who all struggle from writing difficulties. This is something that has been successfully employed in the Write Start program by Case-Smith and colleagues (Case-Smith, Holland, & Bishop, 2011). Here, an occupational therapist was assigned to the classroom, and through co-teaching with the class teacher, implemented a twelve week intervention with two 45 minute sessions per week. The intervention itself involved specific handwriting instruction, self-evaluation and feedback, and was found to be effective in a number of subsequent studies (Case-Smith, Holland, Lane, & White, 2012; Case-Smith, Holland, & White, 2014; Case-Smith, Weaver, & Holland, 2014). Therefore, it is possible to provide effective intervention within the school. However, the costs of employing an occupational therapist, for multiple classes, is a prohibitive factor for the implementation of this type of intervention in many schools.

Therefore, an intervention was designed that could be implemented by other school staff, for example teaching assistants. Whilst being grounded in evidence based practice within clinical settings, the intervention would be a free resource that could be implemented with small groups of children who have handwriting difficulties. The intervention, and the evidence base for each section, is described below. The first aim of the present study was to assess the feasibility of running the intervention in schools, and to identify the barriers to schools running the intervention autonomously. The second aim was to collect feasibility data on conducting baseline and post-intervention assessments that could be used to assess the effectiveness of the intervention in a full trial.

6.2 The intervention

In designing an intervention that was suitable for implementation by school staff, the evidence base from the handwriting literature was assessed, and key evidence-based principals identified. The intervention was also based on a number of principals from the motor learning literature as this has been recommended for effective intervention for children with handwriting difficulties (Wallen et al., 2013). These principals are outlined below, along with how they were incorporated into the intervention.

6.2.1 Testing schedule

A recent systematic review of occupational therapy-led handwriting interventions found that a minimum threshold of 20 sessions of intervention was needed, at a rate of at least two sessions per week, in order for improvements to be seen (Hoy et al., 2011). No similar pattern was discovered for the length of each session which in the successful interventions varied between 20-60 minutes. For the purposes of this study, since the aim was to examine the feasibility of running the sessions themselves rather than looking for measurable improvements, the intervention was run for 5 weeks, 3 times per week, and each session lasted 20 minutes (so that children were not taken out of entire lessons). This was deemed to be sufficient in order to expose any issues with this structure, and with the intervention.

6.2.2 Variability of practice

There is a principal within motor learning theory that suggests 'variability of practice' supports optimal motor learning (Schmidt & Lee, 1988). This principal suggests that the same skill (i.e. using a pen) should be practised in as many different ways as possible in order to learn a movement skill with the ability to transfer to other situations (Levac, Wishart, Missiuna, & Wright, 2009). Therefore, a number of tasks were included in each session within the designed intervention although every intervention session involved practicing writing skills. Each session included two 'pen-skills' activities: one out of a possible five drawing tasks and one out of a possible five handwriting tasks.

Particularly in the case of younger children, reducing a task into its various components has also been found to help with training, as long as these tasks are then integrated into a functional context (Darrah, Law, & Pollock, 2001). Thus, the five 'drawing' tasks included in the intervention were drawing shapes, drawing crosses, completing mazes, colouring in and circling dots. Each task involved skilful pen use and aspects of writing, for example, the 'crosses' activity emphasised the accuracy of drawing lines, with the additional aim to involve similar sensorimotor tasks as the tracing task in the CKAT assessment, which was shown to predict academic attainment in Chapter 4. These skills were then utilised in one of the writing tasks (writing individual letters, writing groups of two or three letters, writing letters that joined similarly, writing whole sentences and planning (and writing) longer pieces of work).

These writing tasks were particularly important since the key finding from a recent meta-analysis on handwriting intervention was that teaching handwriting (rather than related aspects such as phonological awareness or spelling) is necessary for improving legibility and speed of handwriting (Santangelo & Graham, 2015). This also mirrors the finding in a systematic review of 11 handwriting interventions delivered by occupational therapists (Hoy et al., 2011), where it was found that despite the range of approaches taken, it was only the seven interventions which actually included handwriting practice that were effective. Therefore, every intervention session included one of the writing tasks.

6.2.3 Task difficulty

In order to maximise the potential for learning, Guadagnoli and Lee (2004) suggest that there is an optimal task difficulty, again based on principals of motor learning (Schmidt & Lee, 1988). This theory describes how, in order to gain useful feedback, the task must be achievable. However, if the task is too easy, then no useful information will be learned by completing the task. Therefore, for each task, three levels of difficulty were included. The session leader was instructed to pick a level of difficulty for each child that would challenge them, whilst still being achievable.

6.2.4 Cognitive strategies

One area where there is increasing support within the handwriting and motor literature is the usefulness of the development of cognitive strategies (Henderson & Sugden, 1992; Hoy et al., 2011; Levac et al., 2009; Smits-Engelsman et al., 2013; Weintraub, Yinon, Hirsch, & Parush, 2008; Zwicker & Hadwin, 2009). A number of interventions for children with motor difficulties, such as the Cognitive Orientation to Daily Occupational Performance (CO-OP) (Missiuna, Mandich, Polatajko, & Malloy-Miller, 2001; Polatajko et al., 2001) and Neuromotor Task Training (NTT) (Schoemaker et al., 2003) are built around developing task awareness through verbal instructions, and self-evaluation, and these approaches have resulted in improved results on motor skills assessments (Smits-Engelsman et al., 2013). Within the handwriting literature, a number of studies using cognitive strategies (such as imitation, self-instruction, self-evaluation and feedback) have yielded positive results for writing quality (Graham, Harris, & Fink, 2000; Jongmans, Linthorst-Bakker, Westenberg, & Smits-Engelsman, 2003; Zwicker & Hadwin, 2009). A **'model-plan-evaluate'** structure was therefore, built into each task - similar to the process used in the CO-OP motor intervention (Missiuna et al., 2001). The session supervisor begins by modelling the task, explaining explicitly how they are meeting the demands of the desired outcome. They then encourage the children to create a 'plan' of how they were going to achieve this (i.e. self-instruction). Then, after they had performed the task, the child is encouraged to evaluate their own work, and assess how their plan could be changed in order to improve the next time.

This cognitive strategy was built into all of the drawing and writing tasks, with instructions for the session leader about how to model this strategy, how to encourage the children to plan the movements, and what kind of questions could be discussed in the evaluation. In order to increase the variability of practice of this cognitive stage, and therefore encourage transfer to outside the intervention setting, the child also completed an 'other manual activities' task at the end of each session. Again, five options were given: using stickers, using playdough, making necklaces with beads, folding paper and cutting out shapes.

6.2.5 Ergonomic factors

There is evidence that in-hand manipulation is affected by the quality of a child's seated position (Smith-Zuzovsky & Exner, 2004), and that proficient and non-proficient writers significantly differ on ergonomic factors such as body positioning, pen-grip, pen positioning, and consistency of pen grip (Rosenblum, Goldstand, & Parush, 2006). Therefore, each handwriting session began with a 'preparing for handwriting' section, with the aim of encouraging the child to ensure they were in a stable and comfortable position before starting writing. This included seating position, making sure the page was steady, and pen-grip.

6.3 Methods

6.3.1 Research setting

Children from low socioeconomic status (SES) areas consistently show poorer academic outcomes (Sirin, 2005), and higher rates of handwriting and motor coordination problems (Lingam et al., 2009; Potter, Mashburn, & Grissmer, 2013). The City of Bradford is one of the most deprived areas of the UK, according to the Index of Multiple Deprivation (ONS, 2011). Set up to try and address the high levels of childhood morbidity and mortality, the Born in Bradford longitudinal cohort was established in 2007 (Wright et al., 2013). Through links with this project, a group of ten Primary schools in Bradford had approached our research team, concerned about the number of struggling children in their classrooms. This therefore provided the opportunity to introduce this additional support in schools where there were likely to be high numbers of children with handwriting difficulties that could benefit.

6.3.2 Design

The ten schools were recruited to the intervention at the beginning of 2015. Teachers were asked to put forward any child they believed had handwriting difficulties which would benefit from intervention. No more specific inclusion/exclusion criteria were set, since the aim was that the selection and running of the intervention would be as autonomous within the schools as possible.

The intervention was implemented in five schools at a time, in two waves. The schools in the first wave took part in the intervention during the Spring term of 2015 (between March and April), with the second wave of five schools taking part in the intervention in the Summer term of 2015 (between May and June). Allocation of the schools to each wave was decided by the schools themselves, due to their individual availability.

Although it was initially hoped that the effectiveness of the intervention could be measured through collecting outcome data before the first wave, at the crossover point, and at the end of the second wave, difficulties with implementation and data collection meant this was not achievable. Therefore, these testing sessions were used to gather additional feasibility data that could be used to inform any future trial.

6.3.3 Consent and ethical approval

Informed written consent was obtained from Head teachers of the participating schools. As the school staff were ultimately responsible for delivering the intervention, they also obtained informed consent internally from the parents/guardians of children identified to take part, giving them advanced written information about the intervention and their right to opt out should they wish to do so. Ethical approval for the intervention and measuring the outcome variables was obtained from the University of Leeds Research Ethics committee (ref: 15-0089).

6.3.4 Intervention materials and procedure

The background, instructions and tasks for the intervention were contained within a single booklet. The first section contained the evidence background to the intervention, laying out the evidence base for each element (as explained above). The next section included the 'preparing for handwriting' instructions, the 'pen-skills' tasks (5 'drawing' tasks and 5 'writing' tasks), and the 'other manual skills' tasks. The last section of the booklet contained pages that could be photocopied, as required, for the different tasks. This included special paper required for the tasks, such as target paper which was required for the cross drawing task. In addition, a session planner could be used to keep track of which tasks had been completed in each session, and there was a record for the children where they could be given a sticker for every session they completed. The only materials not contained in the booklet were some of the materials required for the 'other manual activities' section, such as beads and thread. However, these tasks were designed so that the only items used were those that would typically be found in schools.

All schools were given ten physical copies (as well as being sent an e-copy) of the intervention booklet at a meeting with a researcher. This occurred for each group of five schools separately, immediately before they started their intervention block. At this session, the session leaders went through the booklet, and any questions regarding implementation were answered and noted. For the purposes of the feasibility study, they were given contact details for the lead researcher. They were told they should contact the researcher if they required any extra training, materials, or had any questions (in which case requests were noted and reported below), but otherwise no extra training was given. This was so that barriers to fully autonomous implementation could be identified.

Each intervention session was structured as a twenty minute block, and occurred three times a week. For the purposes of the feasibility study, this continued for five weeks. Session leaders were instructed to work with small groups of children (although the exact number was left to the schools for this study). The first five minutes of each session was spent on the 'preparing for handwriting' section, described above. The children went through a checklist, provided in the booklet, to ensure they were sat comfortably, and holding their pen correctly.

The next ten minutes were spent on the drawing and writing tasks, with session leaders selecting one drawing task as a warm-up activity (from the choice of five), and one writing activity (again from a choice of five). It was advised in the booklet that, for this feasibility study, each of the five activities should be performed three times each over the five weeks to ensure maximum variability. Finally, the last five minutes was spent on one of the 'other manual activities' tasks.

6.3.5 Outcome measures

Data on the children's baseline ability was collected using two measures. The first of these was to measure handwriting speed at the activity level, using the Detailed Assessment of Speed of Handwriting (DASH) (Barnett, Henderson, Scheib, & Schulz, 2007). The DASH is a pen-and-paper based assessment suitable for use with children over 9 years old either individually or in groups. There are four tasks within the DASH: copying the sentence 'A quick brown fox jumps over the lazy dog' in their best handwriting for two minutes (copy best (CB)), writing the alphabet from memory as quickly as possible for one minute (alphabet writing (AW)), copying the initial sentence in their fastest handwriting for two minutes (copy fast (CF)), and a ten minute free writing (FW) task which involves asking the children to write as much as they could on the topic of 'my life' (see Barnett et al. (2007) for detailed instructions). The DASH is recommended for children over the age of 9. However, for the purposes of this study, all children in years 4, 5, and 6 completed this measure. Some children in year 4 were only 8 years old. However, on the basis that they had still had the same amount of schooling (and therefore exposure to handwriting) as the other children in that year group, they still completed this assessment. The test manual reports good levels of internal reliability (α =.83 - .89) and inter-rater reliability (.99) for this assessment (Barnett et al., 2007). The main outcome measures for this battery were standardised score and percentile score.

The second was to measure functional pen-skill ability, assessed using the Clinical Kinematic Assessment Tool (CKAT) (Culmer et al., 2009). The CKAT battery of fine-motor 'pen-skills' is a tablet based assessment that records detailed kinematic measures (see Culmer et al. (2009) for details of the underlying architecture). In previous studies, the CKAT has been shown to be able to differentiate children's performance on the basis of age, sex and functional ability (Culmer et al., 2009; Flatters, Hill, et al., 2014). The child is asked to complete three tasks: tracking a moving dot (with the outcome as the root mean square error (RMSE) accuracy of the movement), aiming between a series of dots as quickly as possible (with the outcome being the average movement time (MT)), and tracing along a series of paths (with the outcome being penalised path accuracy (pPA) – their path accuracy inflated by the time taken outside the 'ideal' time of 36 seconds, represented by a rectangle that the children were asked to keep pace with). These tasks involve many of the skills involved in writing and drawing, such as applying precise forces to a pen. The outcome variables for each of the three tasks (RMSE, MT and pPA) were then standardised by year of age against a data set of over 1000 children aged 4-11 years who had previously completed the CKAT during two other screening studies (Flatters, Hill, et al., 2014; Hill et al., 2016). The average of these three standardised z-scores were then converted to percentiles to give a total fine-motor score outcome.

Before the first wave of schools took part in the intervention, all children put forward by their teachers in the ten schools were tested by the research team. Each school was visited on a single day, with children brought out from class in groups of around five to work with the research team in a space allocated by the school (often the library or an unused classroom). They were each sat with a researcher and completed the CKAT assessment individually, and then the older group completed the DASH as a group, with one researcher giving the group the task instructions. For the younger children (reception – year 3), this assessment session lasted no longer than 20 minutes, and for the older children, it lasted around 45 minutes.

In order to gain information on the feasibility of using these measures to assess the effectiveness of the intervention in any future trial, baseline performance on the DASH and CKAT was measured for all the children before the first wave of schools started the intervention, after the first wave of schools had completed the intervention, and after the second wave of schools had completed the intervention.

6.3.6 Feedback from schools

An online questionnaire was created (Appendix A), with help from experts in healthcare engagement at the University of Leeds, in order to capture feedback from the session leaders regarding their experiences implementing the intervention. A link to this questionnaire was emailed to the main contact at each school after the second wave of schools had completed the intervention, asking them to forward this to the members of staff who had acted as session leaders. A follow-up email was then sent to the same contact five days later, asking them to remind session leaders to complete this.

6.3.7 Feasibility evaluation

The feasibility of the intervention is discussed first according to the barriers and recommendations for implementing the intervention autonomously in schools. Subsequently, feasibility issues regarding running a future trial of the effectiveness of the intervention in schools will be presented, including school recruitment and attrition, and participant identification and recruitment. In addition, the feasibility of collecting data using the outcome measures is discussed, including barriers to running the testing sessions in the schools, and issues surrounding data management.

6.4 Feasibility results

6.4.1 Barriers and recommendations for autonomous implementation

At both meetings where the booklet was given to staff members, before each wave of intervention, around 30 staff members attended. These were made up of teaching assistants (TAs) and special educational needs coordinators (SENCOs). In response to the online feedback questionnaire, nineteen session leaders completed this. Of these, eight responders were from one school who took part in the first intervention block, with one responder from another school in this block. Seven responders came from staff from a single school in the second intervention block, two from another school, and one from a fourth school. Fifteen of the respondents were TAs, one was a teacher, one was a SENCO and one described themselves as a cover supervisor. Part of the reason for the low number of responders may have been that it was in the last two weeks before the summer holidays, when staff were extremely busy.

There were three issues that were raised during the initial meetings. Firstly, in the meeting with the first wave of schools, session leaders commented a number of the writing tasks would be too difficult to do with the younger children. For the purposes of this study, the schools were told to replace a more difficult writing task with one of the simpler ones if the children could not complete them, and this was also communicated to schools at the meeting with the second wave of schools. Although it was originally intended for one booklet to cover all ages, it is now recommended that the intervention should be split into two difficulty levels, each with five different writing tasks. This would ensure the variability of tasks is maintained for the younger children.

Secondly, some session leaders stated they did not have suitable resources for the 'other manual activities' section, for example, the playdough and beads. It emerged during the session with the second wave of schools where the booklet was distributed that not all schools had access to these materials, and therefore for the purposes of this study a pack was provided to each school containing one set of all these materials. However, it appeared that even within these schools, it was difficult for all of the classes to gain access to these. When asked the question *'Was there any additional support (for example, extra materials/training sessions etc.) you would have found useful when running the intervention?'* in the feedback questionnaire, five respondents mentioned this. For example:

> *"It took time finding resources and it was costly buying some of the resources that were required. (My own money!)"*

Providing materials to all the classes involved in the intervention is clearly not compatible with full schools autonomy, and our aim was to make the intervention as cost-free as possible. Since key in this section is practicing the model-plan-evaluate technique, rather than the tasks themselves, it is recommended that these three tasks (stickers, playdough and threading beads) should be altered, so that no extra equipment is needed. For example, instead of using stickers to make a particular picture, they could draw the same picture instead. Likewise, the playdough task could be altered to creating objects with paper, and instead of the threading task, strips of paper could be weaved together.

Lastly, three of the schools in the second wave of schools asked the researcher to go through an example session with members of staff (or for one school, with a group of children) so that they felt more comfortable running the intervention. These sessions were provided. Again, this was an issue that also came out in the feedback questionnaire. When asked *'Was there any additional support (for example, extra materials/training sessions etc.) you would have found useful when running the intervention?'*, and *'Do you have any final suggestions or comments as to how we could improve the intervention, or make it easier to run?'*, five respondents raised this issue. For example:

> *"Training should of contained some demonstration of how to carry out the activities. The booklet was easy to follow but this would of helped."*

"Better training and more opportunity for questioning about activities and session planning. Eg What you expect to see on the planning sheet and what would be considered valuable information to record from each session."

"Although the handbook was self explanatory i felt some activities would have been understood better if discussed and shown in person"

Again, providing extra training to the schools is not compatible with full autonomy. In order for this not to be necessary, it is recommended that ultimately example sessions in the form of transcripts are included, or possibly online videos.

From responses to the questionnaire, feedback was generally very positive. 94.8% of the respondents agreed or really agreed with the statements *'The background section of the booklet was easy to understand'*, *'It was easy to explain the tasks to the children'*, and *'The children found the tasks enjoyable'*. 78.9% agreed or really agreed with the statement *'It was easy to understand how to run the sessions with the information provided'*. Session leaders also reported that they found it easy to implement the model-plan-evaluate cognitive strategies: 77.7% agreed or really agreed with the statement *'It was easy to use the model-plan-evaluate method in each of the tasks'*.

However, two further issues were identified in the feedback from the questionnaire. Of the nineteen respondents, 68.4% answered 'disagree' or 'really disagree' to the question 'It was easy to stick to the recommended schedule (three twenty minute sessions per week, for five weeks)'. The main reason for this was identified as it being difficult to fit the intervention session into 20 minutes, for example:

"Some of the children in the groups were children who took longer than 10-15 minutes to settle down. This affected how long the activity took and the success of the session."

"It was very difficult to run the intervention within the allocated 20 minutes. This was because the handwriting tasks were quite long."

> *"I think the timing isn't enough. I feel that maybe 30 minutes for each session would have been better as the activities were always rushed."*

Therefore, it is recommended that the intervention sessions should be extended to 30 minutes to help ensure fidelity to the intervention.

The final issue raised was regarding the group sizes that the session leaders worked with during the intervention. The group sizes of the children each session leader worked with had been left to the school to decide. 13 session leaders (68.4%) reported that they worked with groups of 3-4. However, 6 session leaders worked with groups of 5-7 children at a time, and all reported that they found this sized group too big. Therefore, advice should be included in the booklet that group sizes should be kept to a maximum of 4.

6.4.2 Barriers and recommendations for future randomised control trials

6.4.2.1 Recruitment and retention

Of the ten schools that had initially shown interest in the handwriting project, all ten signed up to take part in the intervention. It should be noted that these schools had approached the research team, rather than the research team having to recruit them. However, from this a number of recommendations can be made regarding recruiting schools for future intervention work. These schools were part of the SHINE partnership in Bradford, a consortium of schools which aims to share good practice and development opportunities. This meant that at consortium meeting, there was the opportunity to directly liaise with the head teachers of the schools, who ultimately decide whether an intervention will be run or not. Targeting these types of partnerships for recruitment is recommended, and such groups are increasingly common, for example with the expansion of academy chains – groups of academies in formal collaborative arrangements (Department for Education, 2015).

As a group, the schools in this study had recognised that handwriting problems were a significant issue for many of their students in limiting their ability to succeed. They reported that it was this knowledge about the negative impact of handwriting problems which contributed to their willingness to participate. Therefore, this is something it would be vital to communicate in recruiting schools to any future intervention studies.

Two of the ten schools (20%) dropped out during the course of the study, one from each block of schools. For one of these schools, a changeover of staff resulted in the new intervention lead not being informed as to when to start the study. Therefore, in any future trial of the intervention, it is important to understand the chain of responsibility in the school, in order to ensure that there is clear communication. The other school dropped out due to The Office for Standards in Education, Children's Services and Skills (Ofsted) inspections occurring. The schools are not given advance warning of these inspections, and so it is difficult to plan around them. However, it should be noted that both of the schools reported they would be keen to be part of future research on the intervention.

6.4.2.2 Participant identification and recruitment

515 (393 male) children across the ten schools were initially selected by their teachers to take part in the intervention, which represented 10.38% of the entire school roll of all the schools (n=4961) (see Table 6.1 for demographics).

Table 6.1. Descriptive statistics for each of the ten schools involved in the feasibility study

School	Intervention Group	N % of school roll)	Age mean (range)	Gender (Male:Female)	Handedness (Right:Left)
1	1	31 (12.86%)	7.9 (4.6 – 11.4)	24 : 7	24 : 7
2	1	62 (13.39%)	8.0 (4.5 – 11.3)	46 : 15 (1 not recorded)	54 : 8
3	1	68 (10.00%)	7.8 (4.5 – 11.3)	48 : 20	63 : 5
4	1	65 (14.13%)	7.8 (4.5 – 11.2)	45 : 20	57 : 8
5	1	56 (9.97%)	7.6 (4.5 – 11.4)	46 : 10	49 : 7
6	2	70 (9.29%)	8.0 (4.8 – 11.3)	56 : 14	65 : 5
7	2	23 (5.94%)	8.0 (4.9 – 11.5)	19 : 4	18 : 5
8	2	60 (12.27%)	7.1 (4.6 – 11.1)	46 : 14	51 : 9
9	2	37 (7.91%)	8.0 (4.7 – 11.3)	29 : 8	34 : 3
10	2	42 (9.23%)	7.8 (4.6 – 11.5)	34 : 8	35 : 7
TOTAL		**515 (10.38%)**	**7.8 (4.5 – 11.5)**	**393 : 121 (1 not recorded)**	**450 : 65**

It was then examined whether these children did indeed show impairment in handwriting and/or fine motor skills, by assessing the baseline data on the DASH and CKAT. Within the clinical literature, a score under the 15th percentile is often used to indicate probable difficulties (Sugden, 2006). Therefore, the proportion of children that were flagged up by the DASH and CKAT as having potential difficulties, out of the total number of children identified was examined (see Table 6.2).

Table 6.2. Descriptive statistics for DASH and CKAT at baseline, split by school

Test	School	A	B	C	D	E	F	G	H	Total
DASH	Valid n	14	20	26	20	14	36	18	23	171
	Mean percentile score	28.79	37.60	28.48	27.99	16.74	26.26	20.11	26.39	26.92
	SD percentile score	20.78	31.48	28.69	22.41	16.70	23.58	23.65	24.72	24.89
	n < 15th percentile	5	7	10	6	7	15	11	8	57
	% sample <15th percentile	35.71	35.00	38.46	30.00	50.00	41.67	61.11	34.78	33.33
CKAT	Valid n	29	59	55	52	41	58	21	33	348
	Mean percentile score	28.96	32.60	30.01	26.26	28.83	27.21	41.26	34.29	30.28
	SD percentile score	27.09	23.89	17.88	27.43	23.89	27.76	26.76	22.66	23.89
	n < 15th percentile	7	11	18	19	10	16	1	8	90
	% sample <15th percentile	24.14	18.64	32.73	36.54	24.39	27.59	4.76	24.24	25.86

DASH = Detailed Assessment of Speed of Handwriting; CKAT = Clinical Kinematic Assessment Tool

Average score in the general population represented by a percentile score of 50 on the DASH and CKAT

It can be seen that overall, children performed worse than the general population on both speed of handwriting and pen-skills, with mean scores well below the average. However, as indicated by the standard deviations, there were large differences between the children's baseline ability. In addition, looking at the proportion of children identified as having poor handwriting by their teachers that fell in the bottom 15th percentile, on average only a third of the children would be classified as having 'probable difficulties' for speed of handwriting, and a quarter for fine motor pen skill control.

There was a significant moderate correlation between standardised performance on the DASH, and fine motor pen-skills on the CKAT ($r = .40$, $p < .01$), indicating that many of the children were exhibiting both handwriting speed and fine motor difficulties.

6.4.2.3 Feasibility of collecting data on outcome measures

6.4.2.3.1 Data collection

During the testing sessions, it became apparent that the testing environment varied a huge amount both between the different schools, and within the schools themselves across different testing days. For example, across the three testing sessions for one school, one testing session was in an empty Key Stage 2 (KS2) (years 3-6) classroom, one was in an empty meeting room used by adults, and one in a shared area used by children in year 2. There are a number of issues with this.

Firstly, the fact that in some of the spaces other children were walking past or using the area caused a lot of distractions for the children. Since performance will clearly be influenced by concentration on the tasks, this would make it hard to reliably measure actual performance. Secondly, desk and chair height was not always suitable for all ages. For example, in the school described above the tables and chairs were too tall for all the children in the adult meeting space, and still too tall for those in younger age groups in the KS2 classroom. Performance may have been adversely affected by not being able to sit in their normal writing position, again reducing the reliability of the measures.

Because space for this type of testing is often limited in schools, and in particular since the type of space varies so much between the schools, it may not be possible to be able to reliably measure performance increases between schools. However, it is recommended that, before the intervention starts, negotiations should be held with the school to try and arrange a space that can be used for all subsequent testing sessions, and ensure that this is a space that is closed off from other students.

It should also be noted that language difficulties, such as English not being the children's first language, or not knowing the alphabet by heart, and special educational needs were not recorded for this study. In any future trial, given the focus on outcomes, it will be important to record this data so that these children can be assessed separately if necessary.

6.4.2.3.2 Data management

A number of data management issues were also revealed, which resulted in data being unable to be matched between the baseline and subsequent post-tests. With the two schools dropping out and therefore being excluded from analysis, data was collected on the DASH for 171 children in the remaining 8 schools at baseline 1 (B1), 154 children at post-test 1 (P1), and 134 children at post-test 2 (P2). Of these children, 110 (64.32% of children tested at B1) had data that could be matched at all three time-points. There were 348 children who had data collected at baseline 1 (B1) on the CKAT test of fine-motor skill. At post-test 1 (P1), data was collected on 323 children, however, only 255 (73.28%) of these children could be matched with their data at B1. At post-test 2 (P2), data was collected for 336 children, with data matched for all three time points on 223 children (64.08%). Of the group of children in years 4-6 that completed the CKAT and DASH each time, 136 had valid DASH and CKAT data at B1 (79.53% of B1 children who completed the DASH), and only 72 children had complete data matched at all three time points (42.11% of children completing DASH at B1). Means and standard deviations for both tests at all three time points in Table 6.3 below.

Table 6.3 Descriptive statistics for DASH and CKAT percentile scores at each time point, split by school

Time point	Measure	School	A	B	C	D	E	F	G	H	Total
Baseline 1	DASH	Valid n	14	20	26	20	14	36	18	23	171
		Mean	28.79	37.60	28.48	27.99	16.74	26.26	20.11	26.39	26.92
		SD	20.78	31.48	28.69	22.41	16.70	23.58	23.65	24.72	24.89
	CKAT	Valid n	29	59	55	52	41	58	21	33	348
		Mean	28.96	32.60	30.01	26.26	28.83	27.21	41.26	34.29	30.28
		SD	19.11	21.12	23.46	16.83	19.44	15.33	18.05	23.52	19.93
Post-test 1	DASH	Valid n	14	17	24	20	13	33	10	23	154
		Mean	31.70	37.54	31.97	19.94	23.08	31.05	33.72	22.37	28.73
		SD	19.99	30.86	33.26	24.53	18.86	26.38	31.63	29.42	27.64
	CKAT	Valid n	29	17	55	47	37	69	30	39	323
		Mean	30.83	42.81	29.39	30.89	41.65	38.51	41.20	26.35	34.53
		SD	21.19	24.03	21.66	20.72	23.74	24.56	24.75	20.90	23.19
Post-test 2	DASH	Valid n	26	19	26	21	15	13	9	19	134
		Mean	45.73	20.46	25.07	22.13	32.57	25.08	32.93	26.62	27.39
		SD	28.04	20.83	31.40	18.10	31.07	22.14	30.39	31.09	27.18
	CKAT	Valid n	12	19	58	44	38	70	30	51	336
		Mean	32.44	44.04	26.53	31.81	48.40	48.06	56.92	39.57	40.32
		SD	20.68	24.76	23.85	19.53	24.34	26.32	25.45	23.61	25.51

There were a number of reasons for the problems with matching data at different time points. Firstly, some teachers changed their minds after the initial baseline testing about which children they wanted to include in the intervention, and therefore sent these new children to subsequent testing sessions. It is therefore, crucial for a randomised control trial to ensure that class teachers inform the school contact if they wish to do this, and so the school contact can feed this back to the research team.

Linked to this, the second wave of schools were implementing the intervention during the end of year test period, and for this reason decided not to include year 6 pupils (who were completing their national tests) in the intervention. It should therefore be ensured that neither the intervention period nor the assessment sessions run close towards the examination period.

There was also an issue with matching participant IDs. In this study, unique pupil number (UPN) for each pupil was used as children's study ID. UPNs consist of a letter and 12 numbers, and were used as an easy way for schools to be able to keep track of which children were in the study. The list linking UPN to child's name was kept by the school, and was given to the research team when they came to test. However, the fact this was a paper document resulted in one school not keeping this list of pupils. There was then confusion from the teachers as to which children they had originally put forward and this resulted in some different children being sent. This could be solved by creating, with the school, an electronic copy of the children involved in the testing, and ensuring the school contact at each school has a copy of this pairing names and IDs. In addition, because the UPN was such a long string, it was occasionally entered incorrectly by researchers, and therefore it was difficult to match follow-up data with that collected at baseline. Using an electronic copy of UPNs would also help with this, as researchers could copy directly from this, helping to eliminate input errors.

6.5 Discussion

This study aimed to examine the feasibility of implementing a school-based evidence-led intervention. The intervention was designed to be carried out entirely by the teaching staff in the schools themselves, and a number of barriers to this were identified in this study. In addition, feasibility data for running a future randomised control trial to measure the effectiveness of the intervention was also collected.

Overall, the session leaders reported that they found the intervention easy to run, and the layout and structure of the intervention were regarded positively. Handwriting was a recognised issue within this group of schools, reflected in the fact that on average, over ten percent of children throughout the schools were put forward for the intervention. The intervention was successfully implemented in eight of the ten schools, and the two schools that dropped out (due to external inspections or a new member of staff not realising they had to start), were keen to implement the intervention at another time. Therefore, this intervention shows excellent potential as a method of delivering intervention to groups of children within schools.

Before the intervention is able to be run completely autonomously however, there are a number of changes that may need to be made. For example, the session leaders felt it was difficult to fit the activities in to twenty minutes, and therefore, the session length should be increased to thirty minutes. In order to further reduce the demands on the session leaders, there is also a further option to make the intervention even more flexible by leaving the intensity of the sessions to the schools. It would be made clear in the booklet that a minimum of two sessions is required per week (in line with the recommendations for successful interventions by Hoy et al. (2011), and that overall each child would need to complete 20 sessions. The schools could then run this as sessions every day for four weeks, four sessions a week for five weeks, and so on. However, this is something that would need to be examined to determine whether one level of intensity is more effective than another.

It also may be necessary to create a second version of the booklet for younger children who are still learning their alphabet. Whilst the older children were able to complete all the ‘writing’ activities in the current booklet, the children in the younger age groups were not, which led to the session leaders simply repeating the ‘writing individual letters’ task, which clearly limits the variability of practice. Variability of practice could be introduced in different ways for this group of children. For example, using different writing implements or writing the letters at different sizes. The booklet for the younger children would be altered to give detailed instructions regarding this. The other alteration that would need to be made to the intervention structure is to ensure that none of the tasks required any materials other that pens, pencils and paper. This requires that the tasks in the ‘other manual activities’ section be altered to involve only activities that did not require any other piece of equipment whilst again ensuring variability within each session.

However, the main issue that occurred which would impact on the potential of this intervention was that a number of schools felt that they needed additional training both before running the intervention, and in the feedback questionnaire. One solution that was proposed was to create a number of example scripts of sessions, giving specific examples for each of the tasks, or even online video tutorials. These could then be included as part of the booklet, or freely accessed by the schools online. However, this would require significant development, and until the effectiveness of the intervention is established through a future randomised control trial, then this not practical. Instead, a standardised training session should be developed to provide to each of the schools before the intervention for the randomised control trial. If this was effective, it could then be assessed how best to translate this training into scripts or video tutorials.

In assessing the feasibility of collecting data for a randomised control trial, the single biggest issue was the big differences in testing conditions both between schools and between testing sessions. The outcome measures will always be heavily influenced by the attention of the children taking part, and this lack of reliability would mean that any improvement in a full-scale trial could have been masked. However, the pressures on the space available in schools will always constitute a limiting factor. Therefore, it may not be feasible to measure improvements between schools in a reliable enough way to collapse results between schools. However, if a consistent testing environment can be created for each school individually across testing sessions, so that conditions were as close as possible for each child individually in each testing session, then improvement could be measured for each school individually. This would have to be negotiated with the schools before the first baseline measures are taken. This would allow improvements to be measured in the most reliable way possible and take into account between-school differences in testing.

One thing that should also be taken into account in assessing the effectiveness of the intervention is that there was a huge amount of variation in the baseline abilities of the children selected for the intervention. Overall, the children selected for the intervention did indeed perform below average for their age on both speed of handwriting and fine-motor pen skills, but only between a third and a quarter of the children would traditionally fit the criteria for 'probable difficulties' (Geuze et al., 2001). It would be interesting to assess, when running a future trial on the effectiveness of the intervention, whether improvements in handwriting are observed for any particular group of children based on their baseline skill level. For example, if it is only those children at the lower ability groups that benefit, then teachers may need more support in identifying which children to give the intervention to. Likewise, this type of support may not be intensive enough for those children with the most severe problems. These children may then be the ones that would need to be referred on to clinical help.

To conclude, handwriting difficulties are a widespread problem within schools that may hinder a child's academic potential. There is a real need for evidence-based interventions to be made available to schools to help ease the pressure on professional services. The intervention described here is intended to provide the first intervention step in a graded approach (Sugden & Chambers, 2003), delivered by school staff to larger groups of children, and thereby freeing up professional services for only the most severe cases. Here, a promising method to be able to deliver this type of structured support has been shown, and solutions have been proposed to the barriers identified in this feasibility study. Therefore, the next step for this intervention would be to run a full pilot, including measuring its effectiveness.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

7.1 Introduction

Sensorimotor control involves decoding sensory information and encoding it into motor commands. Therefore, all human interactions with the world involve sensorimotor control. There is a wealth of converging evidence that children who show 'poor motor performance' do worse in many different domains, with evidence for links between poor motor performance and negative physical, social, mental and academic outcomes (Zwicker et al., 2012). However, both the construct of 'poor motor performance', and the clinical movement disorder DCD are poorly defined. Providing a clear framework around which to interpret previous findings was the initial foundation of this thesis (Chapter 2). In addition, the confusion around the assessment of poor motor performance has led to poorly operationalised measurements regarding the negative impact of motor deficits on specific aspects of childhood development. Based on the conclusions from Chapter 2, the next area of inquiry in this thesis was to examine the relation between sensorimotor function and obesity (Chapter 3) and educational attainment (Chapter 4). This inquiry used more precise measures of motor function than previously deployed.

Setting to one side measurement and definitional issues, there is though little doubt that many children are impacted by 'motor problems' - potentially far more children than can be treated within existing clinical services. Therefore, the final aim of the thesis was to explore novel methods of intervention, based on evidence from the sensorimotor learning literature and from results found in the previous experimental chapters. Chapters 5 and 6 reported the findings of two different studies that explored novel approaches to intervention. The results from all of these experiments are summarised below.

7.2 Summary of experimental findings

Motor deficits can be measured at the level of function (sensorimotor control processes), activity (ability on specific tasks), and participation (ability to take part in 'real-life' situations). In Chapter 2 of this thesis, the relation between performance at each of these levels was assessed, using standardised assessments at each level with an educationally referred and a medically referred sample of children. It was found that there was a weak relation between performance at each of these levels as predicted by models that emphasise the complexity of disability and clinical diagnosis. Although it could be argued that the ICF guidelines may be too strict a framework to ascribe to tests of motor difficulties, it is clear that measures such as the three used in Chapter 2 are measuring performance at different levels, and that agreement between these is limited. In the previous literature, these labels of levels of functioning are used almost interchangeably to describe what many of the assessments are indeed measuring. For example, they have measured at the participation level but suggested conclusions at the level of function. What this chapter has shown is the importance of using these terms clearly when drawing conclusions based on a specific measurement.

The contribution of previous studies has been in drawing attention to the central role of movement in most activities of daily living (ADLs). The flip side of this coin is that all ADLs involve both sensorimotor control and higher-level cognitive processes. Thus, a relation between activity deficit and outcome (for example, educational attainment) may simply reflect that the activity contains relevant core elements and does not allow one to conclude that one single element is driving the relation. If a measurement does not isolate a specific process (e.g. sensorimotor processing) whilst keeping other requirements to a minimum, there is no way of knowing whether the performance on the task is due to a particular deficit, or a deficit in any other domain. This provides an explanation as to why there is often very little agreement between performances on different motor tasks. The complex relations between deficits in different domains as well as the added influence of contextual factors, means there is not a simple 1:1 relation between functional and activity level difficulties.

Therefore, previous research that has sought to link ‘motor deficits’ with other negative outcomes based on activity level measures cannot be taken as definitive. Chapter 3 aimed to address this issue in the context of the link between motor function and obesity, and Chapter 4 examined the links between motor function and academic attainment. In examining the previous research, there were a number of recurring issues with the measures of motor ability used in the previous literature. In particular, the fact that overall motor ability it is often based on categorical measures of performance, which is extremely reductive considering that motor function is on a continuum. In addition, scores on individual activities are often grouped together into overarching constructs such as ‘fine’ and ‘gross’ motor activity, despite the fact that performance is often very different on different activities within these domains. This links back to the fact that no activity of daily living involves the motor domain alone.

Chapter 3 found no relation between the measures of motor function and obesity (as indexed by BMI). This may be due to two possible reasons: firstly, that the relation between motor function and obesity does not become manifest in children aged 4-5 years old but appears later. This is a reasonable conjecture considering that children exert increasing independence over their own experiences during primary school (for example, they begin to choose whether to participate in physical activity or not). The benefit to the current study is that the participants (from the BiB1000 cohort) are part of a prospective longitudinal study. Therefore, any emergence of a relation between motor function and obesity can be assessed in future studies. However, if no such relation emerges, it suggests an alternative explanation – i.e. obesity causes poor motor skills because of secondary issues. For example, a displaced centre of gravity, or fingers that are less dextrous because of increased fat. This conjecture would suggest that the motor skills at age 4-5 years will not have a relation with obesity, but obesity at for example, 11 years old will have a relation with poor motor activity. The work reported in this thesis will allow these hypotheses to be tested.

A significant relation between sensorimotor function and academic attainment was found in Chapter 4 in the general primary school population (children aged 5-11 years old). In particular, the tracing task on the CKAT accounted for much of the relation with mathematics, reading and writing attainment scores, and the tracking task showed a weaker relation with mathematics and reading. The likelihood that different neural pathways are involved in these sensorimotor skills may go some way to explaining this.

The results found in Chapter 4 also suggested potential benefits to intervention, particularly in primary schools where a large number of children may experience these functional motor difficulties, and therefore, not be reaching their academic potential. One method that aims to target improving sensorimotor functions are robotic haptic devices. Therefore, in Chapter 5, one such robotic device was tested on a group of children who had shown poor motor performance at the activity and participation levels. This intervention involved many of the same sensorimotor skills involved in the CKAT tasks. However, no transfer of benefit to the CKAT tasks was found that could be attributed to the intervention. It may be that even very small differences in the tasks involved will prevent transfer to other activities being observed. In order to target activities such as handwriting, it may not be feasible to simply target the underlying motor deficits. Instead, it may be necessary to approach intervention as activity-specific (i.e. to improve handwriting you need to target the specific components of handwriting).

Therefore, a very different method of intervention was developed in Chapter 6, with the aim being to create an evidence-based intervention to target handwriting difficulties in schools. Targeting specific underlying functional motor deficits may only help children with those specific difficulties, and as highlighted in Chapter 2, there may be many functional deficits in different combinations that interact to produce the same observed deficit in an activity. Handwriting in particular involves many skills in other domains. Therefore, in order to maximise the potential for this intervention to benefit children with 'handwriting difficulties', the intervention built on principles of sensorimotor learning, but also cognitive strategies and other evidence from a meta-analysis of previous handwriting interventions.

Chapter 6 reported the results of a feasibility study that examined whether this intervention could be run autonomously in schools. Although some changes to the intervention itself are required to make it more acceptable, this method of delivering intervention shows potential. There is now a need to evaluate the effectiveness of the intervention in decreasing these difficulties within school populations. These investigations will need to explore whether the intervention can improve performance at the functional level, at the activity level of handwriting, and the participation level of writing in school.

7.3 Concluding statement

It is clear from the results in this thesis that much work needs to be done to try and ensure that ‘poor motor problems’ are more strictly defined and measured. Children may show problems with their performance on a ‘motor’ activity for many different reasons. This is because the underlying pattern of functional deficits both in the motor domain, and in others, is likely to be complex. By using more rigorous measures of motor function these patterns may begin to be understood. There is no doubt that having difficulties with ‘motor activities’ has huge ramifications on a child’s life and furthering our understanding of exactly what deficits contribute to risk of such difficulties has the potential to transform outcomes for these children. This understanding will hopefully allow increasingly targeted and evidence-informed interventions of the type explored within this thesis.

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APPENDIX A: FEEDBACK QUESTIONNAIRE FOR HANDWRITING INTERVENTION SESSION LEADERS

UNIVERSITY OF LEEDS

Helping handwriting SHINE - feedback questionnaire (copy)

Page 1: Page 1

Introduction

You have been asked to complete this survey because you recently took part in delivering the 'Helping Handwriting SHINE' handwriting intervention.

We would now like to get your views on how the intervention went, and what you think could be done to improve the intervention. This is really important as we aim to keep improving the intervention and make it even easier for schools to run.

This questionnaire should take no more than ten minutes to complete. It may be useful for you to have a copy of the intervention booklet with you whilst you are answering these questions. A pdf copy of this booklet should be attached to the email along with the link to this questionnaire.

All of your answers will remain confidential. If you do not wish to answer one of the questions, just press the skip button, or you can exit out of the questionnaire at any time.

We would like to take this opportunity to say a huge thankyou to everyone involved in delivering this intervention, and hope it has been an enjoyable and worthwhile experience for you, and the children that took part.

Signed,

The Born in Bradford and University of Leeds research team.

Page 2: Demographic Information

1 Which school do you work for?

2 What title best describes your role at the school?

- Teacher
- Teaching Assistant
- SENCO
- Other

2.a If you selected Other, please specify:

3 Which year group were you running the intervention with? You can select more than one.

- Reception
- Year 1
- Year 2
- Year 3
- Year 4
- Year 5
- Year 6

4 On average, how many children were you working with at one time?

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ Other

4.a If you selected Other, please specify:

5 In your opinion, was the size of group that you worked with

Page 3: Background and instructions

The next four questions are about the background and intervention section of the booklet (pages 6 - 9). You may find it useful to have this book with you when answering these questions.

6 Please select the answer that most describes how you feel about the intervention.

Please don't select more than 1 answer(s) per row.

	Really disagree	Disagree	Agree	Really agree
The background section of the booklet was easy to understand	☐	☐	☐	☐
The background section was useful when I was planning the intervention	☐	☐	☐	☐
It was easy to understand how to run the sessions with the information provided	☐	☐	☐	☐

7 Was there any information or materials that you felt were missing from the booklet?

Page 4: Running the sessions

These questions are about running the intervention sessions.

8 How long on average did it take you to prepare for each session?

9 Please select the answer that most describes how you feel about the intervention.

Please don't select more than 1 answer(s) per row.

	Really disagree	Disagree	Agree	Really Agree
The tasks were challenging for the children to do	☐	☐	☐	☐
The tasks were not too difficult for the children to do	☐	☐	☐	☐
It was easy to explain the tasks to the children	☐	☐	☐	☐
It was easy to use the model-plan-evaluate method in each of the tasks	☐	☐	☐	☐
The children found the tasks enjoyable	☐	☐	☐	☐
I believe the intervention had a positive effect on the children's handwriting	☐	☐	☐	☐

It was easy to stick to the recommended schedule (three twenty minute sessions per week, for five weeks)	☐	☐	☐	☐
I was able to run each of the tasks three times during the intervention	☐	☐	☐	☐

10 If you weren't able to do all of the tasks, which ones couldn't you do, and why?

11 Was there any additional support (for example, extra materials/training sessions etc.) you would have found useful when running the intervention?

12 Do you have any final suggestions or comments as to how we could improve the intervention, or make it easier to run?