# A comparison of characteristics, developmental disorders and motor progression between children with and without Developmental Coordination Disorder

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# Abstract

Background and aim. Children with Developmental Coordination Disorder (DCD) have difficulty in the development of motor coordination and with learning new motor skills. Studies demonstrate that children with DCD differ in terms of the nature and severity of their motor difficulties, the incidence of co occurring conditions and family background. However, little is known whether these profiles may relate to motor progression over time. The aim of this study was to describe the profiles of children with and without DCD and track motor progression over time.

Method. The characteristics of thirty-four 7-14 year old children (M=10.07, 85.3% boys) with and without DCD were compared and their motor progression monitored over a two academic years. DCD was identified using DSM5 criteria. The Movement Assessment Battery for Children-2 (MABC-2) was used to classify children as TD (≥25th percentile), having moderate motor coordination difficulties (6-16th percentile) or severe motor coordination difficulties (≤ 5th percentile). The Kaufman Brief Intelligence Test – 2 (KBIT-2) was used to measure full scale IQ. Parent questionnaires were used to gather information on socio economic status and co occurrence of other developmental disorders. We used ANOVA to assess whether there were differences in characteristics between the TD children, children with severe motor coordination difficulties and children with moderate motor coordination difficulties. Linear mixed effect modelling was used to estimate any change in motor performance over time and whether this differed between the three groups of children.

Results. Children with severe motor coordination difficulties had distinct profiles in motor and non-motor domains, lower IQ and a greater likelihood of having associated characteristics of 2 or more developmental disorders. We found significant differences between the poor motor performance of the severe group compared to the other two groups. Longitudinal analyses revealed stable, persistent and lower motor competence for the severe group. The rate of change in motor proficiency for the typical and severe groups was similar. However, the group with moderate motor difficulties gained on average more points per week compared to the typical group and achieved motor scores in the typically developing range over time.

Conclusions. This is one of the first studies to compare the characteristics and rate of motor progression of children with and without DCD using different motor proficiency cut off scores. The children with severe motor coordination difficulties progressed at the same rate as typically developing peers but remained in the severe group over time, whereas the children with moderate motor coordination difficulties caught up to TDC. The results indicate that different intervention may be required according to the nature and severity of the characteristics in both the motor and non-motor domains of children with DCD.

*Keywords: DCD, motor difficulty, motor progression, longitudinal study*

# 1. Introduction

Motor competence is important for day-to-day life and enables independent participation in productivity and leisure activities (Barnett & Hill, 2019; Sugden & Wade, 2019). Motor competence refers to the ability to proficiently execute a wide variety of motor skills, including gross and fine motor skills (Utesch et al., 2016; Burton & Miller, 1998) and the underlying mechanisms such as motor control and coordination (Coppens et al., 2019). Various terminologies have been used in literature to refer to this latent concept, but this paper uses the terms motor competence in alignment with previous studies (Hands, 2008; Rodrigues et al., 2016; Coppens et al., 2019) but the term motor proficiency is also used interchangeably. Typically developing children learn to explore their environment through movement, enabled by motor competence. It is generally accepted that motor competence improves over time with increasing age throughout childhood (Keogh & Sugden, 1985). Typically developing children will have developed a range of fundamental movement skills by 7 years of age, which are the basic units from which to build the more complex skills needed for participation in daily activities (Sugden and Wade, 2013, p179). Furthermore, skills that require control of coordination (such as the development of spatial and temporal accuracy in coincidence timing) have major increases in performance between the ages of 6 and 7 and 12 and 13 years, as do the skills required for manipulation and tasks involving reaction and movement time (Sugden & Wade, 2013, p179).

DCD is a condition characterized by poor motor proficiency that interferes with an individual’s activities of daily living (APA, 2013). It is a serious condition with prevalence estimates ranging from 2-20% of children (Blank et al., 2019), but the rate of 5-6% is the most widely accepted (APA, 2013). DCD can have profound negative impacts on several other developmental domains, such as the cognitive and social-emotional domains (Losse et al., 1991; Dewey et al., 2002; Harrowell et al., 2018) and on their quality of life (Zwicker, Harris & Klassen, 2013; Zwicker et al., 2018). Furthermore, evidence suggests that some of the difficulties associated with DCD persist into adolescence and adulthood (Rasmussen & Gillberg, 2000; Kirby, Edwards & Sugden, 2011; Blank et al., 2019). Missiuna & Campbell (2014) describe DCD as a chronic disability, with the potential to manifest across the lifespan (Barnett, 2008) and therefore deserves attention.

DSM 5 (APA, 2013) is currently used to diagnose DCD. This stipulates four criteria for the diagnosis of DCD. Criterion A: that the acquisition and execution of coordinated motor skills is below that expected given an individual’s chronological age and opportunity for skill learning. Criterion B: that the motor deficits in criterion A significantly and persistently interfere with activities of daily living and impacts on productivity, prevocational and vocational activities, leisure and play. Criterion C: Onset of symptoms is in the early developmental period. Criterion D: The motor skills deficits are not better explained by intellectual disability or visual impairment and are not attributable to a neurological condition (APA, 2013).

However, the criteria are still open to some interpretation. For example, in criterion A the motor proficiency cut off point to identify children with DCD may vary between those at the lowest 5th percentile to those below the 16th percentile on a standardized motor test. Furthermore, different experts advocate different motor proficiency cut off points to identify children with DCD. For example, the 5th percentile is recommended in the Leeds consensus statement (Sugden et al, 2006) but the 16th percentile is recommended in the EACD guidelines (Blank et al., 2019). However, little is known whether these different levels identify different groups of children, but evidence is emerging to suggest that the children with DCD in the lowest 5th percentile for motor proficiency may have distinct broader characteristics. For example, Schoemaker et al. (2013) examined children from a UK population cohort by comparing groups with different severity of motor difficulties to typically developing children (TDC). They found that the children in the lowest 5th percentile of motor proficiency (i.e. those with severe motor difficulties) had lower mean IQ and a higher prevalence of problems in reading, writing, attention, social skills and activities of daily living than those with moderate motor difficulties and TDC. However, little is known whether the children with different levels of motor proficiency progress differently over time.

DCD is often described as a heterogeneous condition because children with DCD can present with diverse symptoms, from abnormal visual perception to difficulty with timing of motor responses (Visser, 2007), which frequently co-occur alongside other developmental disorders (Green et al., 2008; Martin, Piek et al, 2010). Pitcher, Piek & Hay (2003) found a 50% overlap with Attention deficit and hyperactivity disorder (ADHD), Green et al. (2002) found a 73-90% overlap with Autistic spectrum disorder (ASD) and Hill (1998) found a 60% overlap with specific language impairment (SLI). It is therefore difficult to discern what are the observable characteristics and behavioural effects of DCD without screening for other developmental disorders. For example, it is unclear how these relate to motor progression over time.

The opportunity for motor skill learning, is often facilitated in the child’s immediate environment, and is an important aspect of criterion A in the diagnosis of DCD. A child’s family circumstances and the resources available to them can have a profound impact on child development (Smith, Cowie & Blades, 2003), but is can be overlooked in some studies. Noting socio economic status (SES) is one method of trying to account for differences in children’s environments that may impact motor development (Ferreira et al., 2018).

There are reports of varied motor outcomes in longitudinal and intervention studies in DCD, with some children improving, some remaining the same and some deteriorating over time (Cantell et al, 2003; Geuze & Borger, 1993; Knuckey & Gubbay, 1983; Sugden & Chambers, 2007; Green et al, 2008). Yet little is understood why, and therefore, limited predictability is available about which children will make progress either with or without intervention, or whether different groups require different intervention.

Some methodological issues further complicate the investigation of DCD. One of which is whether studies have clear adherence to DCD diagnostic criteria (Geuze et al., 2001; Smits-Engelsman et al. 2015). Another potential problem is the level of cut off motor proficiency score used to identify the sample. Most studies use only ≤15th or ≤16thpercentile and therefore may potentially miss any differences in the characteristics at lower levels of motor proficiency or whether they may progress differently.

The measurement of change in motor proficiency is another topic that appears to have different approaches in the field of DCD. Some studies report statistical difference, for example between pre and post intervention motor scores (Van Waelvelde et al., 2010). Others argue that statistical significance may not translate as functional change and seek to identify clinically meaningful change in motor proficiency. For example, Wuang et al. (2012) chose to identify change as the ‘minimal important difference’ (MID), which was expressed as a 2-point change in total test score. However, the standard measurement error in any test must also be taken into account. Another method to measure change, described as the smallest detectable difference (SDD), was calculated using the standard error of measurement (SEM) of the test, SDD= 1.96 x √ (2x SEM) (Wilson et al., 2016). Yet another method identified ‘the smallest detectable change’ (SDC), defined as the magnitude of change necessary to exceed measurement error (Holm et al., 2013). The Norwegian study by Holm et al. (2013) indicated that, when using MABC-2, level 2, a score of ± 10 total score points was necessary to indicate that real change had taken place using the same assessor over two occasions. This conservative measurement appears to have a more practical application and is more likely to reflect functional change and account for intra-rater reliability. The traffic light category system for identifying motor difficulty using the MABC-2 (Henderson, Sugden & Barnett, 2007) is a recognizable method for categorizing any change in motor proficiency over time. Here green denotes typical motor proficiency, amber denotes moderate motor difficulty and red denotes severe motor difficulty. The MABC-2 is considered to have good psychometric properties for assessing motor functions by the European Academy of Childhood Disability (EACD) and the level of evidence for suitability for diagnosis of DCD rated as moderate to good (Blank et al., 2019).

Although change in motor competence development in TDC has been studied recently (Rodrigues et al., 2016; Henrique et al., 2018; Coppens et al., 2019) it was within the context of physical fitness and only used gross motor measures. All these recent studies found variability in the trajectories of motor competence in TDC between 6-9 years old, which made predictability about later motor competence difficult. However, there was conflicting evidence between the studies about the relationship between motor competence at baseline and change in motor competence over time. Comparison across these studies has proved difficult because of methodological differences. Few studies have investigated trajectories of motor competence in children with DCD. However, a recent longitudinal study by Ruddock et al. (2016) investigated developmental trajectories using growth curve modelling for children with DCD compared to TDC. They investigated online perceptual motor coupling and inhibitory systems in 6-12 year old children with DCD over 2 years. These mechanisms, linked to fast corrective processes, are enabled by a neural mechanism known as the internal model and undergo large changes between 6-12 years (Ruddock et al., 2016). An internal model deficit has been hypothesized to contribute to the motor deficits observed in children with DCD (Wilson et al., 2013). Ruddock et al. (2016) found that the children with DCD had difference in growth curves to TDC and a protracted period of development to achieve online coupling, leading them to conclude that this resulted from a lag in development of motor cognitive networks. However, they used only the ≤15th percentile motor proficiency cut off level to identify children with DCD. There is a dearth of studies investigating the rate of change in motor competence in children with DCD and none that investigate both at the moderate and severe levels of motor difficulties.

Comparison between DCD studies is difficult owing to differences in methodology and statistical analyses. King et al. (2011) argue that the intra- and inter-subject variability, often seen in DCD research, may provide critical information and that the behavioural characteristics may provide valuable insights into the condition. This variability has previously been considered a limiting factor in the analysis and interpretation of behavioural data from children with DCD, yet King et al (2011) suggest that the use of flexible statistical techniques can enable investigation at this level. Another method adopted in DCD research, rather than traditional group comparison, is mixed effect modelling (Cantin et al., 2014; Cairney et al, 2010). The main benefit of this approach is that it allows estimation of population level parameters while taking into account correlation between measures, for example within individuals. It makes use of all the available data as the number and timing of data points do not have to be the same between individuals. It can also handle missing data if they are missing at random.

The design of this study was a prospective longitudinal observational study of children aged 7-14 years. We would expect typically developing children to have achieved fundamental movement skills by age 7 and observe improvement in motor competence within this age span. The first aim was to examine the motor and non-motor characteristics of children with and without DCD categorized into typically developing children, children with moderate motor coordination difficulties and children with severe motor coordination difficulties. The non-motor characteristics included IQ, screening for the presence of co-occurring developmental conditions and noting the SES and family context. The second aim was to track the progression of motor competence over time for evidence of stability or change and assess the rate of change in motor scores. Based on previous DCD research literature we hypothesized that the characteristics of the motor groups would differ by motor competency. However, given the limited research on the rate of change in motor proficiency for children with DCD with different levels of motor competency, no specific hypotheses were formed and the focus of the study was mainly exploratory.

# 2. Method

## 2.1 Participants

Recruitment occurred through mainstream primary and secondary school head teachers and school special needs coordinators, rather than clinics. DCD is not well recognized and frequently under diagnosed (Missiuna et al., 2007; Wilson et al., 2012) so we wanted to recruit any children who had not yet received a diagnosis of DCD, as well as children with a diagnosis of DCD and children who were typically developing. Children aged 7-14 years were eligible for inclusion as typical children will have acquired fundamental movement skills but will still undergo a period of major increase in skills requiring motor coordination (Sugden & Wade, 2013). In addition, children in the UK take external examinations above 14 years and we wanted to avoid any disruption of exam studies. Teachers were asked to identify children that they considered to have motor coordination difficulties and identify children that they considered typically developing. A parent report questionnaire and school records were used to ascertain the absence of neurological disorders, sensory impairments and physical disabilities. Children with developmental disorders, permissible for inclusion in the DSM 5 diagnosis for DCD, were included. For this study these included ASD, SLI and ADHD. The children either had an existing diagnosis or screened positive at or below the 5th percentile cut off during the screening process. All the children were screened for DCD using the DCD ’07 (Wilson et al., 2009) and for associated characteristics using the Children’s Communication Checklist 2nd edition (CCC-2) (Bishop, 2003) for ASD and SLI and the Swanson Nolan and Pelham–IV (SNAP IV) (Swanson et al., 2001) for ADHD and oppositional defiant disorder (ODD). The Kaufman Brief Intelligence Test 2nd edition (KBIT-2) (Kaufman and Kaufman, 2004) was administered to all children to ascertain cognitive performance level. However, children attending special school full time were not eligible for inclusion. The parents of 34 children consented to the project, which resulted in a sample of 29 boys and 5 girls with mean age 10.07 years (SD 1.66). One school had an integral resourced unit that catered for children with Autistic spectrum disorders (ASD). The sample was somewhat weighted towards those with ASD and their siblings as a result of the recruitment procedure. There were 13 children with co occurring characteristics, which included ADHD, ASD, language impairment and ODD. Due to long waiting lists for therapy in the area, none of the children received occupational therapy or physiotherapy for motor control during the project. The University of Leeds Ethics Committee approved the study. Informed written consent was obtained from the parents and verbal assent obtained from all children.

## 2.2 Measures

2.2.1 Motor performance.

Motor performance was assessed using age bands 2 and 3 from the Movement ABC-2 test (MABC-2; Henderson, Sugden & Barnett, 2007). This individually administered performance test consists of eight items divided into three sections: Manual dexterity (three items), Aiming and Catching (two items) and Balance (three items). The raw score of each item can be converted into a standard item score and these can be combined to form a total standard score, which has a corresponding percentile rank. A ‘traffic light’ system was used to identify children with motor impairment. Those whose score fell at or below the 5th percentile (red) were regarded as having severe motor difficulty, and those whose score fell between 6th -16th percentiles (amber) were classified as moderate motor difficulty, whilst those with scores above 25th percentile (green) were classified typically developing. The MABC-2 has UK norms and is reported as reliable and valid for use with children (Henderson, Sugden & Barnett, 2007; Schulz et al., 2011; Ellinoudis et al., 2011) and has a good to excellent test-retest reliability (Blank et al., 2019).

### 2.2.2 Impact of motor coordination difficulties on daily activities.

The Developmental coordination disorder questionnaire (DCD Q 07) (Wilson, Crawford et al., 2009) was used to report functional problems attributed to the child’s motor performance and support DSM 5 DCD diagnostic criteria.This is a 15-item parent questionnaire, designed for children 5-15 years old, posing questions about the child’s control during movement, fine motor/handwriting and general coordination. The scores are ranked 1-5, with 1 relating to ‘not like your child’ and 5 relating to ‘extremely like your child’. Scores range from 15-75, but scores between 15-55 indicate ‘suspect DCD’ for children aged 8-9 years 11 months and for those aged 10-15 years scores 15-57 indicate ‘suspect DCD’. The psychometric properties are acceptable (Pannekoek et al., 2012). The DCD-Q ‘07 has Canadian norms, but is the DCD questionnaire validated most frequently in the literature (Blank et al., 2019). Only the DCD-Q ’07 total score was used in this study.

### 2.2.3 Associated characteristics (AC) in attention and communication.

The Children’s Communication Checklist 2nd edition (CCC-2) (Bishop, 2003) is a 70 item multiple-choice questionnaire that screens for communication problems in children aged 4-16 years and takes 5-15 minutes to complete by parents or anyone who knows the child well. The checklist can screen for language impairment, identify pragmatic impairment in children with communication problems and help to identify children who may merit further assessment for autistic spectrum disorder (ASD) (Bishop, 2003). The CCC-2 has robust reliability, internal consistency and good inter-rater reliability (Norbury et al., 2004).

The Swanson Nolan and Pelham–IV (SNAP IV) (Swanson et al., 2001) is a screening test to identify symptoms of attention and behavioural difficulties and can be completed by parents. The 26 item short form of SNAP IV assesses attention deficit and hyperactivity disorder (ADHD) core symptoms of hyperactivity/impulsivity (9 items) and inattention (9 items), along with symptoms of oppositional defiant disorder (ODD) (8 items). Items are rated on a four-point scale 0 (not at all) to 3 (very much) to obtain the subscale scores. Only scores above the 95th percentile are considered clinically relevant (Bussing et al., 2008). The psychometric properties of SNAP-IV are robust and the predictive validity of SNAP–IV is good when parents score inattention above 1.8 and hyperactivity above 2.4 (Bussing et al., 2008).

### 2.2.4 Cognitive performance.

The Kaufman Brief Intelligence Test 2nd edition (KBIT-2) (Kaufman and Kaufman, 2004) is an individually administered, brief measure of verbal and nonverbal intelligence for ages 4-90 years old. It takes 15-30 minutes to administer and has good reliability and validity (Kaufman & Kaufman, 2004). The verbal score contains two subtests, verbal knowledge (60 items) and riddles (48 items) and the non-verbal sub-test is matrices (46 items).

### 2.2.5 Socio economic status.

Lower socio economic status (SES) is widely known to have a deleterious impact on the development and wellbeing of children and adolescents and is largely determined by variables such as level of parental education, marital status and income (Letourneau et al., 2011). Level of maternal education is commonly used in studies, for example Houwen et al. (2017), but car ownership and eligibility for free school meals are also good indicators of SES (King, Law et al., 2003; Michelson, 2006). Low SES is a potential confounding variable for motor development. A parent questionnaire included details about parent employment, car ownership, free school meals, number of siblings with developmental disorders and level of maternal education, as these were considered important factors in SES of the families with children with DCD.

### 2.2.6 Change in motor performance over time.

MABC -2 tests were repeated for each child with the aim of obtaining three data points. Change in motor performance over time was taken as the difference in the child’s MABC 2 total score between time one and time three. A clinically significant change in motor performance was noted using the smallest detectable change (SDC), as advocated by Holm et al., 2013). This is a 10-point difference (either positive or negative) in MABC-2 total test score. A further measure was any change in the traffic light category obtained by the child category of MABC-2 (Henderson, Sugden & Barnett, 2007) at time point three.

## 2.3 Procedure

Each child’s parent or caregiver completed the questionnaires. The same experienced occupational therapist individually tested all children at the baseline measurement using the MABC-2 and the KBIT-2. Test duration lasted between 45 and 60 minutes and was completed at school. The children who met the DSM 5 criteria for DCD were identified and any children who screened positive for ADHD, ODD, ASD and SLI were also identified. The children were then classified according to their motor performance, using the MABC-2 score, into three groups. A group with severe motor coordination difficulty (red) who scored ≤5th percentile on MABC-2, a group with moderate motor coordination difficulty (amber) who scored 6-16th percentile and a group with no motor coordination difficulty (green), the typically developing children (TDC) who scored ≥ 25th percentile. Repeated motor assessments, undertaken by the same assessor, occurred in the summer and winter terms for a total of three data points for each child over two academic years. All the children were not tested at the same time to allow time for the same examiner to test, but the children were tested in the same term. For example, winter term for data point 1, summer term for data point 2 and winter term for data point 3.

## 2.4 Data Analysis

The first research aim was to examine the motor and non motor characteristics of children with and without DCD categorized into groups of TDC, children with moderate motor coordination difficulties and children severe motor coordination difficulties. The group characteristics for continuous data were compared using one-way analysis of variance (ANOVA). Assumptions of normal distribution and equal variance were tested. Pairwise comparison was undertaken and post hoc analysis using Tukey or Games Howell test, where homogeneity was violated. An additional comparison using Kruskall-Wallis non-parametric equivalent of the ANOVA was also employed due to the non-random small sample. Fischer’s exact test was used for categorical data. We used IBM SPSS statistics 22 for baseline data analysis. For all analyses, significance levels were set at .05 to examine large effect sizes r = 0.70 (d=1.5), a sample of a minimum of 8 per group was sufficient for a power of 0.8 (Hinkle et al., 1994).

The second research aim was to track the progression of motor competence over time for evidence of stability or change and assess the rate of change of motor scores.

We fitted a linear mixed effects model to the motor score data adjusted for school and age at baseline. School was treated as a categorical variable and age at baseline was treated as continuous variable with a linear relationship with motor scores. We centered age at age 7, the minimum age in our dataset. We included a categorical variable for motor ability group at baseline, and a continuous variable for time since baseline to estimate the average change in motor ability scores in the study population per week. To capture the correlation between measurements within individuals we included a random intercept and random slope. In a second step we added an interaction between time since baseline and motor ability group to assess whether the rate of change differed between groups of different motor ability. We used a likelihood ratio test to evaluate this using the conventional α=0.05 as the cut-off for significance. We refitted the final model using restricted maximum likelihood. Significance statements about individual parameters are based on Wald tests and confidence intervals are based on a normal approximation. We conducted the analysis in R using the *nlme* package (Pinheiro et al., 2020) for the analysis.

# 3. Results

Table 1 shows the characteristics of the children screened for DCD and co-occurring disorders. Some of the children who scored ≤5th percentile on DCDQ ‘07 (i.e. suspect DCD) did not meet the DSM5 motor difficulties criteria for DCD (as assessed by the MABC2). Additionally, some children who had moderate motor coordination difficulties had scores >5th percentile on DCDQ ’07 and so did not meet the DSM5 criteria for DCD either. However, all the children who had severe motor coordination difficulties (≤5th percentile on MABC2) also scored ≤5th percentile on DCDQ ‘07 and so met the DSM5 criteria for DCD (see Table 1). Furthermore, 90% of the children with severe motor coordination difficulties either screened positive for, or had a diagnosis of, one or more co occurring developmental disorders. Whereas, despite data missing for 2 children, 50% of the children with moderate motor coordination difficulties screened positive for a developmental disorder and also 29% of the children without motor difficulties screened positive for a developmental disorder.

(Table 1 here)

## 3.1 Comparison of motor groups at baseline

Table 2 shows a comparison of the means and standard deviations of the age, IQ and MABC2 subtest scores of the children grouped by severe motor coordination difficulties, moderate motor coordination difficulties and typical developing.

(Table 2 here)

### 3.1.1 Contextual data and group characteristics.

The groups did not differ significantly either in their eligibility for free school meals (a proxy measure for SES) or the number of siblings with a developmental disorder, Fischer’s exact test *p*= .540 and *p*= .891 respectively. However, there was a significant difference in the number of associated characteristics of other developmental disorders between the groups, Fischer’s exact test *p*< .001. Eighty percent of the group with severe motor coordination difficulties screened positive for two or more associated characteristics of other developmental disorders (see Table 1). A one-way ANOVA revealed no significant difference between the groups for age F (2, 31) = 2.646, *p*= .087, partial eta squared = .146.

### 3.1.2 Cognitive performance.

One-way analysis showed that the difference between the KBIT-2 composite IQ score differed significantly between the groups F (2, 31) = 8.864, *p*= .001, partial eta squared = .364 (see Table 2). Pairwise comparison showed the group with severe motor difficulties had the lowest mean IQ and differed from the typically developing group (*p*= .001). The group with moderate motor difficulties had a lower mean IQ than the typically developing group, but Tukey post hoc analysis showed that the difference was not significant (*p*= .126). There was no significant difference between mean composite IQ scores for the group with severe motor coordination difficulties and the group with moderate motor coordination difficulties (*p*= .137).

#### 3.1.2.1 verbal and non-verbal IQ.

There was a significant difference in KBIT-2 verbal IQ score between the groups F (2, 31) = 13.726, *p*< .001, partial eta squared = .470. Pairwise analyses revealed that both the group with severe motor coordination difficulties and the group with moderate motor coordination difficulties had lower mean verbal IQ scores than the group of TD children (respectively *p*= .001 and *p*= .012), confirmed by Tukey post hoc analysis. No significant differences were found between the group with severe motor coordination difficulties and the group with moderate motor coordination difficulties (*p*= .097). The difference between the groups for KBT-2 non-verbal IQ did not reach significance F (2, 31) = 3.119, *p*= .058, partial eta squared = .168.

### 3.1.3 Motor performance.

The difference between the groups for MABC-2 total score was significant F (2,31) = 71.35, *p*< .001, partial eta squared = .882. Pairwise comparison showed that all groups differed significantly from each other, which was confirmed by Games-Howell post hoc analysis (*p*< .001).

#### 3.1.3.1 manual dexterity

The difference between groups for manual dexterity was significant F (2, 31) = 45.50, *p* < .001, partial eta squared = .746. Pairwise comparison showed that the mean manual dexterity for the group with severe motor coordination difficulties was lower and differed significantly from both those of the group with moderate motor coordination difficulties (*p* = .001) and the group of TD children (*p* < .001), confirmed by Tukey post hoc analysis (respectively *p* = .003 and *p* < .001). It also showed that the group with moderate motor coordination difficulties had lower manual dexterity than the typically developing group and that the difference was significant (*p* < .001), and was confirmed by Tukey post hoc analysis (*p* < .001).

#### 3.1.3.2 aiming and catching

The difference between groups was significant for aiming and catching F (2, 31) = 13.61, *p* < .001, partial eta squared = .467. Pairwise comparisons showed that the group with severe motor coordination difficulties had significantly lower mean scores than both the typical group (*p*< .001) and the group with moderate motor coordination difficulties (*p* = .012), and was confirmed by Tukey post hoc analysis (respectively *p* < .001 and *p*= .031). There was no significant difference between the group with moderate motor coordination difficulties and the typical group (*p* = .100).

#### 3.1.3.3 balance

One way ANOVA showed a significant difference between the groups for balance F (2, 31) = 46.52, *p* < .001, partial eta squared = .750. Pairwise comparison showed that the group with severe motor coordination difficulties had significantly lower means scores than both the typical group (p < .001) and the group with moderate motor coordination difficulties (*p* = .001). This was confirmed by post hoc analysis (respectively *p* < .001 and *p* < .001). The difference between the group with moderate motor coordination difficulties and the typical group did not reach significance (*p*= .051), and this was confirmed by post hoc analysis (*p*= .123).

Kruskall-Wallace non-parametric tests concurred with the all the ANOVA results.

## 3.2 Motor progression over time.

A total of 34 children were tested at baseline, 31 at data point 2 and 29 at data point 3 from 5 different schools. The children lost to follow up included one boy from the group with severe motor coordination difficulties, two (boy and girl) from the group with moderate motor coordination difficulties and two TD boys. Three of the children changed schools during the project and two at a secondary school were lost to follow up because of timetabling difficulty. The time between testing ranged from 17 to 107 weeks mean 31.67 (standard deviation 28.92). When extracting 3 outliers the range was 17-25 weeks, mean 20.62 (standard deviation 2.98).

In the longitudinal analysis we found a significant interaction between motor proficiency groups and time since baseline (likelihood ratio test p-value: 0.03) therefore our final model included this interaction. Table 3 gives the estimated parameter values. We found no significant difference in motor scores by age and school. At baseline children in the groups of moderate and severe motor coordination difficulties had on average 14.43 (95% CI -24.45 - (-4.41) and 40.64 (95% CI: -48.06 - (-33.21)) points lower motor scores than those in the typical group, respectively. There was no significant change in the motor scores per week in the typical group (estimate: -0.06 point per week (95% CI: -0.28 - 0.17)). Children in the group with moderate coordination difficulties gained on average 0.61 points in motor scores per week (95% CI: 0.16 - 1.06) compared to the typical group. Thus, their motor scores increased on average by 0.55 (95% CI: 0.24 – 0.87) points per week. The rate of change in the severe group did not differ significantly from that in the typical group.

(Table 3 here)

Figure 1 shows motor scores by age and by time since baseline.

(Fig 1 here)

Table 4 shows the children who obtained the smallest detectable change (SDC) ±10 point MABC-2 total score.

The difference in the smallest detectable change (SDC) in motor scores between the groups was significant, Fischer’s exact test *p*= .005. This indicated a clinical change in motor performance. The children in the group with moderate motor coordination difficulties all (100%) improved their motor score, whereas only 20% of the typical group improved. Only 22% of the group with severe motor coordination difficulties improved motor scores. However, this was of insufficient magnitude for them to change motor category as seen in table 5.

(Table 4 & 5 here)

# 4. Discussion

## 4.1 Main findings

The first aim was to examine the motor and non-motor characteristics of children with and without DCD categorized into typically developing children, children with moderate motor coordination difficulties and children with severe motor coordination difficulties.

We screened all children in the sample for other developmental disorders (ASD, ADHD and SLI), which we called associated characteristics because not all diagnoses had been confirmed by a paediatrician. We found significant difference between the groups and importantly, the children with severe motor coordination difficulties had higher prevalence of 2 or more ACs than the other two groups. Other studies have found increased prevalence of co occurring disorders in children with low motor competence. Lingam et al. (2010) studied a large UK population cohort of 7-year-old children and found that children at risk of DCD ≤ 15th percentile of motor proficiency were likely to have additional characteristics of other developmental conditions. These included difficulties with attention, social skills and reading and spelling. Schoemaker, Lingam et al., (2013) explored the prevalence of additional disorders further by examining if the severity of motor difficulties related to co–occurring disorders and problems in children at risk of DCD. They used logistical regression in a large UK population based cohort (n=6959). They found that 7-9 year old children with severe motor difficulties (n=289) had a 20-25% higher risk of problems in ADL, attention, handwriting, reading and social cognition, even when accounting for IQ and parent related confounding variables. Furthermore, they found that children with moderate motor difficulties (n=951) had a 5% higher risk than TDC (n=5719) in these other developmental domains, except for spelling and social cognition. This appears to support our findings that the children in the lowest 5th percentile, i.e. those with severe motor coordination difficulties, have the greatest risk of co-occurring disorders or problems. However, 85% of our sample was recruited from a school with an integral ASD resource unit and, due to the recruitment procedure, the sample was weighted to those with ASD. Eighty percent of our group with severe motor coordination difficulties and 28% of the group with moderate motor coordination difficulties had two or more ACs and even the group with typical motor development had 29% of children with one AC. This is higher than would be expected in the general population, but nevertheless illustrates the higher prevalence of comorbidity in the group with severe motor coordination difficulties.

Gillberg (2010) also noted a higher prevalence of co-occurring disorders in a Swedish population sample of children with neurodevelopmental/ neuropsychiatric disorders but suggested that they are difficult to separate and share genes, environmental risk factors and symptoms. Environmental risk may be measured as SES. This is a potential confounding variable in measuring motor competence, since opportunity for practice and experience are important in the development of motor skills (Rosenbaum, 2010; Sugden & Wade, 2013). It was therefore important to note any differences between the groups at baseline and we used the proxy measure of receipt of free school meals. Gillberg (2010) suggests that children with more severe disorders are more likely to encounter additional disorders as well as social disadvantage and we expected to find this in our study. Indeed, 60% of the group with severe motor difficulties received free school meals. However, statistical analysis revealed no significant difference between the groups in receipt of free school meals in our sample. This may have occurred because the majority of children in the sample came from a school in an area of deprivation and was overrepresented by children who received free school meals in all motor groups.

The majority of previous studies have compared children with DCD below the 15th percentile of motor proficiency to TDC and some have reported lower IQ in the DCD groups (Losse et al., 1991; Cantell et al., 2003). However, this study analyzed the groups with different motor proficiency separately and noted that the children in the group with severe motor coordination difficulties had significantly lower mean composite IQ and verbal IQ scores than the children in the typical motor group (*p*< .001 and *p*< .001 respectively). Furthermore, the children in the group for moderate motor coordination difficulties had lower mean verbal IQ scores than the typical motor group (*p*= .012) possibly indicating that this group also had difficulties outside the motor domain. Interestingly, the difference between the groups for non verbal IQ did not reach statistical significance (*p*=.058). This may reflect the small sample size and may have resulted from the sample including a higher representation of children with ASD, who characteristically have higher non-verbal IQ than verbal IQ (Joseph, Tager-Flusberg & Lord, 2002). Nevertheless, future studies should investigate children with both severe and moderate motor coordination difficulties for IQ and potential learning problems. Co-occurring disorders may be an important factor in the lower IQ found in children with DCD, as other studies have also found that children with DCD and comorbidity have lower IQ scores. For example, Flapper and Schoemaker (2013) found significantly lower IQ in 5-8 year old children with DCD co-morbid with SLI than those with SLI alone. They used DSM IV criteria and ≤ 15th percentile on MABC to identify DCD, but also distinguished children ≤ 5th percentile. They found that the majority (66%) of the sample of children ≤ 5th percentile of MABC was co-morbid for SLI and DCD. This would indicate that children with DCD with severe motor coordination difficulties are at higher risk of having additional learning problems. IQ is thought to be an important variable in the development of motor competence (Sugden & Wade, 2013), but whether poor motor competence affects IQ or vice versa is outside the scope of this paper.

The nature of difficulties in DCD is notoriously heterogeneous in motor and non-motor domains. Since motor symptoms are core to the condition (APA, 2013), comparison of the motor subtests was revealing. The children in the group with severe motor coordination difficulties differed significantly from both the group with moderate motor coordination difficulties and the typical motor group across all subtests, indicating severe difficulty in all motor areas. This finding is partially supported by Kirby et al. (unpublished) who examined 150 children with DCD in the lowest 5th percentile on MABC and found that the majority (56%) had low scores in all subtests (Sugden & Wade, 2013).

In contrast the children in the group with moderate motor coordination difficulty in this study, only differed significantly from the typically developing group in manual dexterity. Manual dexterity tasks, such as the pegboard require accuracy, speed and perceptual abilities (Keogh & Sugden, 1985) and relate to visuo-motor temporal integration (Nobusako et al., 2018). A neural mechanism, known as the forward or internal model, is thought to facilitate this by predicting the outcome of movements before the sensorimotor feedback becomes available thus permitting a rapid online correction (Nobusako et al., 2018). Moreover, visuo-motor integration dysfunction has been reported in children with DCD (Ruddock et al., 2016) and it is hypothesized that the motor deficits observed in DCD could be attributable to an internal model deficit (Wilson et al., 2013). Certain neural pathways are associated with the internal model and a recent meta-analysis of DCD research by Fuelscher et al. (2018) concluded that children with DCD (mainly aged 9-10 years) showed reduced magnitude of activation in five regions of the brain and increased activation in the thalamus compared to controls during tasks of manual dexterity, seemingly lending support to this hypothesis. Poor manual dexterity can result in problems with ADL including dressing, writing and utensil use and impact negatively on everyday life, so follow up and possible intervention for children with moderate motor coordination difficulty will be important to avoid these negative consequences.

Visuo-motor integration improves with increasing age in typical children (Sugden & Wade, 2013; Ruddock et al., 2016) and has a significant relationship to manual dexterity (Ruddock et al., 2016; Nobusako et al., 2018). In our study the children in the group with moderate motor coordination difficulties achieved scores in the typical range for manual dexterity (and all subtests for motor proficiency) by the end of the study, seeming to support the notion of a developmental lag for this group. It is possible that poor manual dexterity is an important indicator to monitor for potential problems. A study by Nobusako et al., (2018) appears to support a relationship between manual dexterity and visuo-motor temporal integration ability. They investigated 132 TDC aged 4-5 years using hierarchical multiple regression analysis and showed that both manual dexterity and age significantly contributed to visuo-motor temporal integration, as expected. However, there was no interaction between age and manual dexterity leading them to conclude that manual dexterity was a significant predictor of visuo-motor temporal integration ability in children, regardless of age. This may be of importance for the identification and possible choice of mode of intervention for children with DCD, but further study is required with older children.

The lower mean IQ level and greater number of associated characteristics evident in the group of children with severe motor coordination difficulties result in a much higher risk of motor and non motor difficulties in everyday life. However, the results of this study and others (Schoemaker, Lingam et al., 2013); Flapper and Schoemaker, 2013; Lingam et al., 2010) show that the children in the group with moderate motor coordination difficulties also appear to be at risk of motor and non motor problems and should not be overlooked.

The second aim was to track the progression of motor competence over time for evidence of stability or change and assess the rate of change in motor scores. The different motor groups in this study followed different patterns of progression. Veldhuizen and Cairney (2015) recognized that, with repeated testing, cases could change to non-cases and vice versa, which can be challenging for longitudinal studies. However, they also suggested that this could provide the opportunity to study change over time within and between cases. In the current study the children in the group with moderate motor coordination difficulties all improved and changed category to typical motor competence by time 3. Furthermore, some children in the typical group decreased in motor competence by time 3 and finished in the category for moderate motor coordination difficulties. In contrast, the children in the group for severe motor coordination difficulties all remained in the same category. A traditional view is that a child with typical motor development will remain on a similar norm-referenced rank within a standardized motor test over time (Darrah et al., 2009). However, this has been challenged by a number of authors, who state that the development of motor competence during childhood is characterized by a high degree of inter-individual variations (Stodden et al., 2008; Rodrigues et al., 2016; Henrique et al., 2018, Coppens et al., 2019).

Motor differences were clearly evident at baseline for this study, yet also remained over time for the children with severe motor coordination difficulties. The persistence of motor difficulties is recognized in the diagnostic description of DCD and is estimated to effect 50-70% of adolescents with DCD (APA, 2013). Barnett, Law and Stuart (2019) reviewed progression of children with DCD into adolescence across previous longitudinal studies and found an overall rate of 56.4% persistence of motor difficulties (based on 156 individuals). Clearly the persistence of motor difficulties is a serious problem leading one to agree with Missiuna & Campbell (2014), who described DCD as a chronic disability. However, there is also clear implication that 30-50% of children with DCD improve their motor competence over time.

The findings from the study by Cantell et al. (2003) indicated that the children with milder motor problems appeared to make more progress than those with severe problems. A finding also supported by this study, as the results showed that the children in the group with moderate motor coordination difficulties appeared to progress differently to the other two groups in terms of both rate of change and change of motor category. Their change in motor competence was both statistically significantly different from the other groups (Fischer’s exact test = 0.05) and clinically significant, since they all reached a score in the typically developing range by time 3.

A closer look at other studies investigating rate of change in motor competence helps our interpretation, despite some conflicting results. For example, Coppens and colleagues (2019) followed typically developing Belgian schoolchildren aged 6-9 years over 2 years using standardized motor tests and found average positive change in motor competence. However, using linear growth curve analysis, they found significant variability in the trajectories of change in motor competence among individual children. Although 96.6% of the sample improved their raw scores, only 30% made sufficient progress to keep up with expected motor development, with respect to age and sex related norms. However, they found no significant relationship between motor competence at baseline and change in motor competence over time in this typically developing sample. Unfortunately, reasons for this can only be speculated as the SES of the children was not reported and the opportunities for experience and practice for skill development is uncertain. They did find that age at baseline was negatively associated with change in motor competence; the older children demonstrated higher motor competence at baseline and smaller change in motor competence. However, the groups in our study did not differ significantly in age. Nevertheless, this study illustrates variable trajectory in motor competence in typically developing children.

Henrique et al., (2018) also found variability when they examined the trajectories of gross motor competence in typically developing 6-9 year old Portuguese children over 4 years. They aimed to identify if children had stable or unstable consistency in high or low motor competency using standardized motor tests. Stability was identified when a child consistently stayed in defined category over time. They found strong instability in individual trajectories from 6-9 years of age, which made group predictions about gross motor competence at later ages difficult. However, they found that stability in the lower competency groups was higher than the upper competency groups, suggesting that low motor competency children tended to maintain their relative position, putting them at risk of potential adverse effects on health. This was also supported by our study, but contradicted by that of Coppens et al. (2019). Unfortunately, neither study reported SES or the context of their sample children and used different statistical analysis, which makes direct comparison difficult.

Similarly, Rodrigues and colleagues (2016) noted different developmental trajectories in typically developing Portuguese children, aged 6 years, when followed over four years. They focused particularly on the rate of change. They used multi level modelling of the changes in fitness and motor competence and individuals were nested within their respective rate of change groups. They labeled low, average and high rate of change in fitness and non-standardized motor competence tests. Since there is no description of motor competence at baseline it is difficult to directly compare with the other studies. Interestingly, they reported that children in the low rate of change group actually decreased their performance over time. Although all groups improved in speed and agility, the low rate of change group showed decrease in performance in all other tests and demonstrated higher odds for being overweight after four years.

From these studies we can conclude that stable and unstable trajectory and rate of change appear important in the outcome for the development of motor competence. All of the aforementioned studies examined only gross motor competence and included only typically developing children aged between 6 and 9 years, but all identified a group of children at greater risk of adverse effects of low motor competence. Hands (2008) found that children aged 5-7 years with low motor competency tended to remain low, despite wide variability, and not catch up with their peers after 4 years.

Each of the three groups in the present study displayed variability in motor progress, in common with the studies on typically developing children. However, the rate of change in motor scores was significantly greater in the children who started in the group for moderate motor coordination difficulties, they appeared to have a ‘spurt’ and catch up with their typically developing peers. The sample size was too small to derive firm conclusions, but evidence from other studies indicates that some children with motor difficulties catch up later and perform at a typical level (Visser, 1998; Cantell et al., 2003). Moreover, Cantell et al. (2003) found that this particularly applied to those with milder motor difficulties. One suggestion is that a marked improvement in sensorimotor skills in children with motor difficulty indicates that the children suffered from a neurodevelopmental delay rather than a structural deficit (Visser, 1998). It is possible that this was the case in the present study and these children were able to take advantage of experience and opportunities in their environment to improve their motor performance, whereas the children in the group with severe motor coordination difficulties could not improve in the same time scale because of an underlying deficit. Only larger random population samples will be able to determine if this pattern is generalizable. Ruddock et al. (2016) favoured neuro maturational delay as an explanation for the catch up observed in children with DCD from their findings on the developmental trajectories for coupling online control and inhibitory mechanism in children 6-12 year old with DCD. However, they did not obtain separate results for the children scoring ≤ 5th percentile. It is possible that in this current study the improvement in manual dexterity scores observed in the group with moderate motor coordination difficulties by time 3 could plausibly be explained by maturation of the internal model neural mechanisms. Further research into rate of motor progression in children with different motor competencies is required.

Barnett et al. (2019) comment that in DCD research the tendency to studies describing mean group performance rather than individual trajectories over time has led to more knowledge about motor performance than motor development in DCD and perhaps now is the time to start to address this trend. Of course other factors are important in motor competence, such as self-perception and willingness to take part in physical activity (Stodden et al., 2008; Cairney et al. 2005) and opportunity for practice (Sugden & Wade, 2013) and future studies should also take these into account.

## 4.2 Study implications

Our findings provide evidence that children with DCD with severe motor coordination difficulties (≤5th percentile MABC-2) are at the greatest increased risk of having characteristics of associated difficulties wider than their motor problems. Our data and earlier studies (Schoemaker et al., 2013; Flapper & Schoemaker, 2013) suggest that careful screening of this group of children is imperative to assess for additional learning needs and to provide support for any social and communication difficulties in order to ameliorate some of the potential poor academic outcomes. Furthermore, the children in the group with severe motor coordination difficulties showed relative stability in motor competence and did not improve significantly over time or catch up. They remained in the same low motor proficiency category anddid not significantly differ in rate of change in motor score per week to the TDC in this study, indicating relative stability in both groups. This suggests that early intervention is required for the children with severe motor coordination difficulties in order to avoid further detrimental effects of the impact of poor motor competence on participation in daily life (Zwicker et al., 2013; Zwicker et al., 2018). A review by Preston et al. (2016) found task orientated motor skill intervention to be the most effective for children with DCD, indicating that they benefit from targeted intervention.

Whilst the data on the motor trajectories for the children in the group with moderate motor coordination difficulties (6-16th percentile MABC-2) cannot be generalized, the finding that they progressed at a faster rate than the other motor groups and caught up to TDC without intervention poses some interesting theoretical questions about the nature of neuro maturation and motor competence for these children. The question of whether there was catch up because of a developmental lag (Visser, 1998; Ruddock et al., 2016) or whether they constitute a different group remains unanswered. More studies are required specifically examining the trajectories separately for children with moderate and severe DCD, whilst screening for co-occurring conditions, to investigate whether they constitute separate groups and learn motor skills in different ways.

The data in this study focused on motor competence over time. Ideally future studies should include other factors thought to impact on the development of motor competence outcomes, such as self-efficacy and perceived competence and engagement in physical activity (Stodden et al., 2008).

## 4.3 Study limitations

Whilst we had extensive screening and background information for all the children in the study, it was a small non-random sample and so the representativeness to DCD and TDC population samples can be questioned. However, adherence to DSM 5 criteria for DCD diagnosis was an important strength. Effect sizes were calculated for estimating sample size for baseline characteristics group comparison, however, the moderate group did not meet the minimum number required. In addition, 5 children were lost to follow up, 1 from the group with severe motor coordination difficulties, 2 from the group with moderate motor coordination difficulties and 2 from the TD group. It is possible that the results obtained could be due in part to the impact of small sample size on the power of statistical analysis conducted. Effect sizes from prior studies on trajectories of motor competence levels for children with DCD over time were not available, so no data could be used to estimate the sample size for this study. Power issues remain an important limitation of exploratory studies using small sample sizes, but they are nevertheless useful for exploring theoretical concepts.

A possible limitation of this study is that physical growth and daily physical activity were not measured and so the possible moderating and mediating effects of these could therefore not be included in the analysis. Future studies examining motor competence trajectories should consider including these variables.

Another limitation is the recruitment method using the SENCO in schools and the influence of the ASD resourced unit attached to one school. This led to an over representation of children with ASD in all motor groups and particularly in the ≤ 5th percentile group and an under representation of girls. Nevertheless, the detailed information on the children’s characteristics will provide a useful basis for future studies into motor trajectories for children with DCD and associated disorders.

# 5. Conclusion

This is one of the first studies to investigate both the detailed characteristics of children with and without DCD and different levels of motor competence and the difference in rate of change in motor competence over time. It shows that the children with severe motor coordination difficulties may have higher occurrence of associated difficulties and that they may not change their level of motor competence over time in relation to TDC, despite a similar rate of change in motor proficiency to their typically developing peers. They therefore remain motor impaired and lagging behind and may require targeted and specific intervention. On the other hand, the children with moderate motor coordination difficulties may progress at a different rate and catch up to their typically developing peers. This requires further investigation to understand the causal mechanisms and may indicate that different intervention is required dependent on the nature and severity of motor and non-motor characteristics and the rate of change in motor proficiency.

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**Table 1**. Characteristics of the study participants

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Child** | **Age** | **Gender** | **DCDQ ≤ 5th percentile** | **CCC2 ≤5th percentile** | **Snap IV ≤5th percentile** | **MABC 2 percentile score** | **Met all DSM5 criteria DCD** |
| 1 | 10 | M | **Suspect DCD** | Typical score | **Suspect ADHD** | 37 | No |
| 2 | 10 | M | **Suspect DCD** | Typical score | Prob not ADHD | 25 | No |
| 3 | 10 | M | missing | **ASD diagnosis** | missing | 5 | ? |
| 4 | 10 | M | **Suspect DCD** | **ASD diagnosis** | **Suspect ADHD** | 1 | Yes |
| 5 | 10 | M | **Suspect DCD** | **Suspect ASD** | **Suspect ADHD** | 0.1 | Yes |
| 6 | 8 | M | **Suspect DCD** | **Suspect ASD** | **Suspect ADHD** | 0.1 | Yes |
| 7 | 8 | M | **Suspect DCD** | **Suspect ASD** | **Suspect ADHD** | 0.1 | Yes |
| 8 | 7 | M | **Suspect DCD** | **Suspect ASD** | **Suspect ADHD** | 2 | Yes |
| 9 | 10 | F | Prob not DCD | Typical score | Prob not ADHD | 25 | No |
| 10 | 11 | F | Prob not DCD | Typical score | Prob not ADHD | 16 | No |
| 11 | 8 | M | Prob not DCD | **Suspect SLI** | Prob not ADHD | 50 | No |
| 12 | 8 | M | Prob not DCD | Typical score | Prob not ADHD | 25 | No |
| 13 | 10 | M | **Suspect DCD** | Typical score | Prob not ADHD | 5 | Yes |
| 14 | 9 | M | Prob not DCD | Typical score | Prob not ADHD | 25 | No |
| 15 | 8 | M | Prob not DCD | Typical score | **Suspect ODD** | 9 | No |
| 16 | 10 | M | Prob not DCD | Typical score | Prob not ADHD | 9 | No |
| 17 | 9 | M | **Suspect DCD** | Typical score | Prob not ADHD | 37 | No |
| 18 | 7 | M | Prob not DCD | Typical score | Prob not ADHD | 75 | No |
| 19 | 11 | M | prob not DCD | Typical score | Prob not ADHD | 50 | No |
| 20 | 10 | M | **Suspect DCD** | Typical score | **Suspect ODD** | 37 | No |
| 21 | 10 | F | Prob not DCD | Typical score | Prob not ADHD | 16 | No |
| 22 | 13 | F | Prob not DCD | Typical score | Prob not ADHD | 84 | No |
| 23 | 14 | M | Prob not DCD | Typical score | Prob not ADHD | 91 | No |
| 24 | 13 | F | missing | missing | missing | 16 | ? |
| 25 | 12 | M | missing | **ASD diagnosis** | missing | 16 | ? |
| 26 | 11 | M | Prob not DCD | missing | Prob not ADHD | 25 | No |
| 27 | 10 | M | Prob not DCD | Typical score | Prob not ADHD | 63 | No |
| 28 | 9 | M | Prob not DCD | Typical score | Prob not ADHD | 50 | No |
| 29 | 7 | M | **Suspect DCD** | **ASD diagnosis** | **Suspect ADHD** | 50 | No |
| 30 | 8 | M | **Suspect DCD** | **ASD diagnosis** | **Suspect ADHD** | 0.1 | Yes |
| 31 | 10 | M | **Suspect DCD** | **ASD diagnosis** | Prob not ADHD | 25 | No |
| 32 | 7 | M | **Suspect DCD** | **ASD diagnosis** | **Suspect ADHD** | 0.5 | Yes |
| 33 | 9 | M | **Suspect DCD** | **ASD diagnosis** | Prob not ADHD | 9 | Yes |
| 34 | 10 | M | **Suspect DCD** | **ASD diagnosis** | **Suspect ADHD** | 0.1 | Yes |

Note: MABC2 = Movement Assessment Battery for Children 2nd edition, DCDQ = Developmental Coordination Disorder questionnaire 2007, CCC2 = Child Communication Checklist 2nd edition, SNAP IV = Swanson, Nolan & Pelham questionnaire, TD = typically developing, ASD = Autistic spectrum disorder, ADHD = Attention deficit hyperactivity disorder, ODD = Oppositional defiance disorder, DCD = Developmental coordination disorder, SLI = Specific language impairment

**Table 2**

*Comparison of mean (+SD) Age, IQ and MABC-2 scores between the groups with severe motor coordination difficulties, moderate motor coordination difficulties and TD*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Group based on motor coordination difficulties Statistical test results | | | | | | |
|  | Severe  ≤5th MABC2 | Moderate  6-16th  MABC2 | TD  ≥25th  MABC2 | ANOVA | Pairwise comparison | Post Hoc Tukey or Games-Howell |
| Age in months | 109.7  ± 14.3 | 129.1  ±19.3 | 124.9  ± 19.9 | *P=*.087 |  |  |
|  |  |  |  |  |  |  |
| MABC2 total score (SD) | 34.4  ± 12.9 | 61.86  ± 3.7 | 77.47  ± 7.7 | *P=*.001\* | S<M<TD | *P*<.001 |
|  |  |  |  |  |  |  |
| Manual  Dexterity  (SD) | 10.7  ± 4.1 | 17.86  ± 4.5 | 26.06  ± 3.9 | *P=*.001\* | S<M<TD | *P*<.001 |
|  |  |  |  |  |  |  |
| Aiming &  Catching  (SD) | 10.00  ± 2.8 | 15.14  ± 4.2 | 18.12  ± 4.3 | *P=*.001\* | S<TD *p=*.001  S<M *p*=.012  M<TD *p*=.100 | *P*<.001  *P*=.031  *P*=.223 |
| Balance  (SD) | 14.7  ± 6.92 | 28.86  ± 4.0 | 33.29  ± 3.6 | *p*=.001\* | S<TD *p*=.001  S<M *p*=.001  M<TD *p*=.051 | *P*<.001  *P*<.001  *P*=.123 |
|  |  |  |  |  |  |  |
| KBIT-2  Composite IQ  (SD) | 78.6  ± 17.2 | 91.29  ± 21.5 | 106.53 ±14.6 | *P*=.001\* | S<TD *p*=.001  S<M *p*=.137  M<TD *p*=.053 | *P*=.001  *P*=.293  *P*=.126 |
|  |  |  |  |  |  |  |
| Verbal IQ  (SD) | 80.7  ± 13.9 | 92.57  ± 15.8 | 109.47 ±13.4 | *P*=.001\* | S<TD *p*=.001  S<M *p*=.097  M<TD *p*=.012 | *P*<.001  *P*=.261  *P*=.031 |
| Non-verbal IQ  (SD) | 81.4  ± 19.6 | 91.86  ± 22.6 | 101.23  ± 19.2 | *P*=.058 |  |  |

Note: S= group with severe motor coordination difficulties ≤5th percentile on MABC2, M = group with moderate motor coordination difficulties 6-16th percentile on MABC2, TD = typically developing group ≥25th percentile on MABC2. Key \* = significance to .05

**Table 3**

*Estimated parameter values*

|  |  |  |
| --- | --- | --- |
|  | Point estimate  (95% confidence interval) | *p*- value |
| Intercept | 74.65 (67.28 – 82.03) | <0.01 |
| Age | 0.01 (-2.65 - 2.66) | 1 |
| School 1 | reference |  |
| School 2 | 3.54 (-16.82 - 23.89) | 0.72 |
| School 3 | 15.97 (-5.27 - 37.22) | 0.13 |
| School 4 | 18.67 (-3.6 - 40.94) | 0.097 |
| School 5 | 4.73 (-12.83 - 22.3) | 0.58 |
| Typical motor ability group | reference |  |
| Moderate motor ability group | -14.43 (-24.45 - (-4.41)) | <0.01 |
| Severe motor ability group | -40.64 (-48.06 - (-33.21)) | <0.01 |
| Time since baseline | -0.06 (-0.28 - 0.17) | 0.62 |
| Interaction time since baseline : Moderate motor ability group | 0.61 (0.16 - 1.06) | <0.01 |
| Interaction time since baseline : Severe motor ability group | 0.26 (-0.11 - 0.62) | 0.16 |
| Standard deviation for random intercept | 7.34 (4.89 – 11.03) |  |
| Standard deviation for random slope | 0.30 (0.15– 0.61) |  |

**Table 4**

*Motor change expressed as smallest detectable change (SDC) T3-T1 (MABC-2 total score) over time by group*

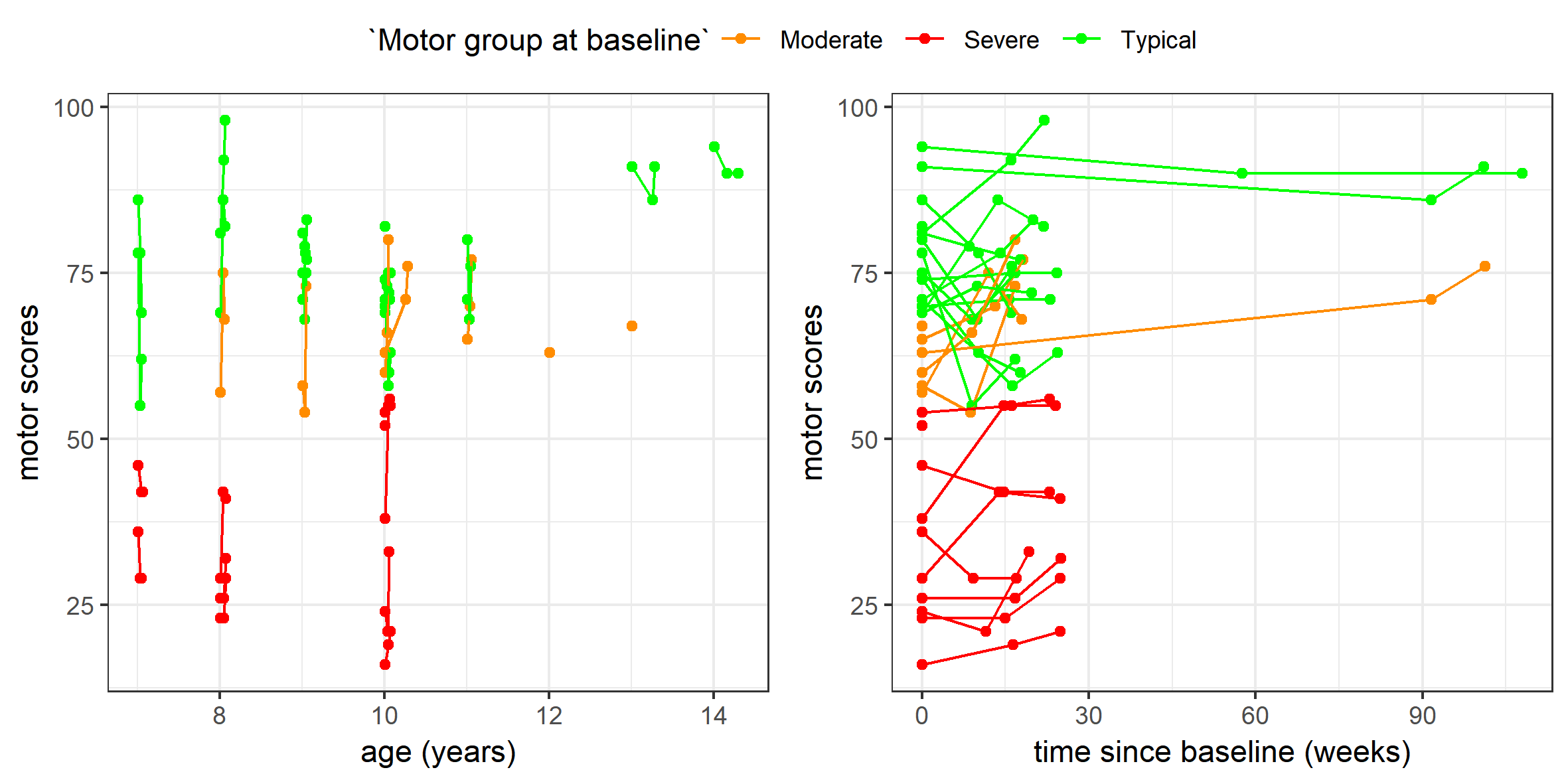
|  |  |  |  |
| --- | --- | --- | --- |
|  | SDC ≥10 points on MABC2 total score (Holm et al., 2013) | | |
| Groups | Improved | Same | Deteriorated |
| Red group severe motor difficulty (≤5th percentile MABC-2) n=9 | 2 (22.2%) | 7 (77.8%) | 0 (0%) |
| Amber group moderate motor difficulty (6-16th percentile MABC-2) n=5 | 5 (100%) | 0 (0%) | 0 (0%) |
| Green group no motor difficulty (≥ 25th percentile MABC-2) n=17 | 4 (23.5%) | 9 (53%) | 4 (23.5%) |

**Table 5**

*Change of MABC-2 traffic light motor category at data point 3*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Red Severe at T3 | Amber Moderate T3 | Green  None at T3 | Category change | Missing data |
| Red  at T1  n=10 | 9 | 0 | 0 | 0% | 1 |
| Amber  at T1  n=7 | 0 | 0 | 5 | 100% | 2 |
| Green  at T1  n=17 | 0 | 3 | 14 | 17.65% | 0 |

*Key Red=* ≤5th percentile MABC-2, Amber=6-16th percentile MABC-2, Green=≥ 25th percentile MABC-2



***Figure 1***

*Plot.1 Representation of age by motor group at base line and Plot.2 Individual motor trajectories over time on MABC-2 total score*