The prenatal, postnatal, neonatal, and family environmental risk factors for Developmental Coordination Disorder: a study with a national representative sample

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Highlights:

- Obstetric and environmental factors both predict DCD independently;
- Male gender and BMI are risk factors for DCD;
- Placenta previa and placental abruption are independent risk factors for DCD;
- Preterm birth is an independent risk factor for DCD;
- Parents' education and one-child status are independent risk factors for DCD.

Abstract

Knowledge of obstetric and environmental influences on Developmental Coordination Disorder (DCD) helps provide increased understanding of the mechanisms underlying the disorder. However, the literature to date has not adequately examined the obstetric and environmental risk factors for DCD in a population-based sample. The current study was therefore conducted to explore the prenatal, perinatal, neonatal, and family environmental risk factors for DCD. A total of 2185 children aged 3-10 years from a national representative sample in China were included; the Movement Assessment Battery for Children-2 was used to assess motor function, and a questionnaire was completed by parents. DCD was identified in 156 children according to the DSM-5 criteria. Multilevel logistic regression was used, and comparisons were made between the DCD and non-DCD group. The results confirmed that male sex, BMI score, preterm birth, and some prenatal conditions are significant risk factors for DCD. Parents' education level and one-child status as two significant environmental risk factors for DCD appear largely independent of other risk factors in the Chinese population. This study provides an opportunity to explore the etiology of DCD and suggest potential assessment, monitoring and intervention programs for DCD that could be examined in the future.

1. Introduction

Developmental Coordination Disorder (DCD) is characterized by difficulties in the execution and coordination of body movements which cannot be accounted for in terms of intellectual impairment or identifiable physical or neurological disorder (American Psychiatric Association, 2013). Children with DCD display difficulties with fine and/or gross body movements such as handwriting, doing up shoelaces, participating in ball sports and riding a bicycle. They are also observed to frequently trip and bump into things and these movement difficulties have a negative impact on their everyday life (Wilmut, Du, & Barnett, 2015). Studies have shown that 1.4-19% of school-aged children are diagnosed with the condition depending on the selection criteria used (Zwicker, Missiuna, Harris, & Boyd, 2012), with boys more likely than girls to have the disorder (Chow, Henderson, & Barnett, 2001; Kourtessis, Psalti, & Kioumourtzoglou, 2008; Engel-Yeger, Rosenblum, & Josman, 2010; Hua, et al., 2014a; Larsen, Mortensen, Martinussen, & Andersen, 2013).

The etiology of DCD is still largely unknown. Research has continued to suggest that this disorder may be related to central nervous system pathology, however, the motor learning process is complicated and evidence from analysis over different levels (behavioural, cognitive, and neural) is mixed, and the mechanisms underlying DCD is not conclusive (Zwicker, Missiuna, Harris, & Boyd, 2012; Blank, et al., 2019). To help generate hypotheses regarding etiology and help identify children at the highest risk of DCD, we now turn to the risk factors for DCD in this literature review.

A number of studies have investigated the association between particular pre-, peri-, and neonatal factors and DCD. Research in this area has focused on broad aspects including mothers' weight status, gestational age, birth weight, neurological conditions, inflammation, autoimmune reaction, and other pregnancy-specific conditions. Studies have associated later diagnosed DCD with factors such as postnatal steroid exposure, longer duration of ventilation, more days on oxygen, and significant retinopathy of prematurity (Zwicker, et al., 2013), as well as maternal age, threatened abortion, fetal distress during labor, preterm birth, chronic lung disease, and newborn pathological jaundice (Hua, et al., 2014a). However, another two cohort studies (Larsen, Mortensen, Martinussen, & Andersen, 2013; Holsti, Grunau, & Whitfield, 2002) found no difference in prenatal, perinatal or neonatal variables between DCD and non-DCD groups. Other studies have focused on children who were born prematurely or born with extremely low birth weight. For instance, Goyen and Lui (2009) found that prolonged rupture of membranes (PROM) and retinopathy of prematurity (ROP) were significantly associated with DCD in extremely premature (≤29 weeks) or extremely low birthweight children (≤1000 g) at the age of 8 years. Davis et al (2007) found postnatal steroid exposure to be associated with DCD in extremely low birth weight infants (<1000g) or very preterm (<28 weeks) at school-age; whereas Cooke (2005) found that only low gestational age was associated with poor motor outcomes consistent with DCD in a cohort of very premature infants (<32 weeks). Nevertheless, premature birth and low birth weight have generally been found to be significantly associated with DCD; however, no consistent results have been identified for other pre-, peri-, and neonatal conditions related to DCD in the previous studies.

With all of the studies mentioned above, a non-maternal factor, children's body weight status was also identified to predict DCD. In a systematic review, Hendix, Prins, and Dekkers (2014) assessed the association between DCD and body weight status of children. They reported that, in all cohorts reviewed, children with DCD had higher BMI (body mass index) scores compared with controls. One explanation of the association between weight status and DCD could be that children with DCD perceive themselves to be less competent in motor skills and less likely to participate in physical activities (Cairney, Hay, Faught, & Hawes, 2005; Green, et al., 2011); while another explanation suggests that certain social-economic-status (SES) factors may underlie the link between body weight status and poor motor skills (Gomez & Sirigu, 2015).

The effect of SES factors on motor skills has received more attention recently, however, the reasons for such an impact are elusive. Some SES factors such as lower levels of parents' education and family income have been reported to predict the lower levels of motor development of children (Freitas, Gabbard, Caçola, Montebelo, & Santos, 2013; Cohen, Morgan, Plotnikoff, Callister, & Lubans, 2014). It has been suggested that some SES risk factors can probably modify the environmental factors which directly influence motor development, such as environment affordances, access to sports activity and equipment, quality and nature of physical education (Freitas, Gabbard, Caçola, Montebelo, & Santos, 2013; Giles-Corti & Donovan, 2002; Humbert, et al., 2006; Gomez & Sirigu, 2015; Venetsanou & Kambas, 2010). However, because there is also a high correlation between the SES factors and obstetric factors such as premature birth and low birth weight (Shah, 2010), SES itself might not directly impact on DCD. The literature to date has not yet adequately examined the obstetric and SES environmental risk factors for DCD together with population-based data. Therefore, although numerous factors have been associated with DCD, their examination in isolation in previous studies increased the likelihood that some confounders might be missed. A study including both obstetric and SES environmental risk factors, while controlling for sex and body weight status of children is needed to clarify how the risk factors work together to predict DCD. This is necessary to identify the main mechanisms responsible for DCD and to suggest potential interventions that could be further explored in the future.

The aim of this study was, therefore, to investigate potential prenatal, perinatal, neonatal, and family environmental risk factors for DCD in 3-10-year-old children in China, using data from a large national representative population-based cohort. We wanted to examine: (1) the relationship between sex, body weight status, and DCD; (2) how obstetric characteristics, including pre-, peri-, and neonatal factors were associated with DCD; and (3) how family environmental factors were associated with DCD. Finally, we wanted to develop a model with a broader set of associated risk factors for DCD including both obstetric and environmental factors.

2. Method

2.1. Participants

This study was part of a broader project to develop Chinese norms for the Movement ABC-2 Test for children aged 3-10 years. This required a stratified sampling plan to ensure the sample was representative of the Chinese population. Data from the 2010 National Census in China provided the basis for stratification by geographic region, age, sex, and social economic status (SES). Since China is considered as a mono-ethnic country (Central Intelligence Agency, 2018), ethnicity was not included as a stratification variable. The target population was children aged 3:0-10:11 years from urban areas of China. Children from only urban areas were recruited because over half of China's population resides in urban areas (World Bank, 2016).

The sampling plan defined a cell structure that identified the appropriate number of children for each cell. The cells were defined in terms of 7 levels of geographic region, 2 levels of sex, 10 levels of age, and 4 levels of parental educational level. A minimum target sample size of 2000 was determined by the requirements for calculating norms for the new Chinese version of the MABC-2. A total of 2185 children from 51 nurseries and schools over the country were recruited for the study.

The 2010 Census divides China into 7 geographic regions: Northeast China, North China, East China, South China, Southwest China, Northwest China, and Central China. The number of children required for each cell of the sample is in accordance with the proportions of the Chinese population between age 3:0-10:11 years living in each region according to the 2010 Census. Table 1 shows the breakdown of the number of children targeted and recruited in each geographic region.

(insert Table 1 here)

Within the overall cell structure, children were sought whose demographic characteristics best fitted the requirements of each cell in terms of sex and age from 3:0-10:11 years inclusive. At the age of 3 and 4, a 'cell' is divided into two to provide data for half-year groups (Henderson, Sugden, & Barnett, 2007). Thereafter, a 'cell' comprised a whole-year group, giving a total of 10 levels of age. For each cell, an equal number of children were expected to be recruited. According to the 2010 Census, the proportion of the Chinese population between boys and girls is the same for all 10 age levels. Table 2 shows the breakdown of the number of children actually recruited in each age and sex group. The education level of the parents was used to indicate SES. Information on the educational level was obtained from parental consent forms. An effort was made to ensure that the proportion of children of parents from each educational level would be proportionate to the distribution of these educational levels in the equivalent age group within the population at large (Table 3).

(insert Table 2 here)

(insert Table 3 here)

Within each geographic region, several nurseries and schools were sampled to include children of all ages and represent SES of the region according to the 2010 Census, and invitations to participate in the project was made by email and telephone to nursery and primary schools chosen to be representative of our targeted sample. Consent forms and instructions for distributing these for whole classes of children were delivered to participating nurseries and schools. Consent was obtained from both nurseries/schools and parents. Verbal assent was also provided by each participant.

2.2. Materials

A range of assessments was used to apply the four DSM-5 diagnostic criteria for DCD (American Psychiatric Association, 2013). For criterion A, the Chinese version of the Test component of the Movement Assessment Battery for Children – 2nd Edition (MABC-2) was used. The MABC-2 Test is reviewed and recommended in the most recent international guidelines on DCD (Blank, et al., 2019). It has been reported to have good test validity and reliability in the Chinese population (Hua, Gu, Meng, & Wu, 2013; Wuang, Su, & Su, 2012). The 5th percentile was taken as a cut-off point to denote motor skill below the level expected for the individual's chronological age. There are eight tasks: 3 tasks measuring manual dexterity (posting coins/placing pegs; threading lace; drawing); 2 tasks measuring ball skills (throwing/aiming and catching); and 3 tasks measuring balance (one or two leg balance; walking along a line; jumping or hopping). For each task, a raw and a standard score[1] was obtained. Parent questionnaires were designed to identify whether a significant motor impairment impacted on the child's daily living ("do you think the movement difficulties adversely affect the child's daily life in classroom learning /recreational activities/self-esteem/social interaction?") (criterion B), whether onset of the motor difficulty was in early childhood ("do you think the movement difficulties of your child can be noticed from an earlier stage of the life?") (criterion C), and also determined that the motor difficulties were not due to a known neurological impairment or intellectual disability ("do you think your child has any neurological impairment or intellectual disability? ")(criterion D). A telephone call was also made to all parents of children with Movement ABC-2 performance at or below 5th percentile to make the diagnosis of DCD.

Information about risk factors in the prenatal, perinatal and neonatal period was acquired from questionnaires completed by the children's parents. Preeclampsia is a medical condition characterized by high blood pressure and significant amounts of protein in the urine of a pregnant woman. Anaemia is a decrease in the number of red blood cells (RBCs) or less than the normal quantity of hemoglobin in the blood. The

[1] The standard score for each participant on Movement ABC-2 was caculated based on the UK norms published in the test manual.

term fetal distress refers to the presence of signs in a pregnant woman—before or during childbirth—that suggests that the fetus may not be well. Preterm birth is defined as regular contractions of the uterus resulting in changes in the cervix that start before 37 weeks of pregnancy. Low birth weight (LBW) is defined as a birth weight of a live-born infant of less than 2000g regardless of gestational age. Chronic Lung Disease of Infancy (CLDI) represents the final common pathway of a heterogeneous group of pulmonary disorders that start in the neonatal period. Newborn pathological jaundice usually appears between 24 and 72 h of age, peaks by 4–5 days in term and the 7th day in preterm neonates and disappears by 10–14 days of life. Additionally, Body mass index (BMI) was calculated according to the child's weight and height. A child with BMI >18 was indicated as being overweight. An adult with BMI > 25 was indicated as being overweight.

Information on the environmental risk factors was also obtained from the questionnaires completed by children's parents. Information including hours of outdoor activities per week, sibling status (whether the participant is the only child or has sibling(s) in the family), the main caregiver of the child (parents/grandparents/nanny/others), education level of mother and father, and family income was collected.

2.3. Procedure

Permission was obtained from the test publisher to translate the record forms and test instructions from English into Chinese; common use of terms (e.g., the name and description of tasks in Chinese translation) from the earlier publication in Chinese was used in the translation. A back translation was undertaken by independent translators, and the original and back-translated versions were equivalent in meaning. An expert panel with experienced experts in relevant fields was convened to review every step towards the translation of Movement ABC-2. All 35 assessors had proficient experience in conducting psychological assessments with children in a similar age range, and all assessors were trained to individually administer the Movement ABC-2 Test with a two-day training program.

In all cases, children were assessed individually in their own nurseries/schools. The testing duration for each child was 30-40 minutes. Detailed instructions were delivered to parents to make sure they understood the questions in the questionnaires and contact information was given to parents with any enquiry. The children scored at or below the 5th percentile with Movement ABC-2 were interviewed by an assessor by telephone for diagnosis of DCD. Ethical approval was obtained by the Institutional Review Board (IRB) of the National Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University.

2.4. Data analysis

Data were missing for 94 participants; therefore their data were excluded from the final analysis. Among the rest, 156 of 2091 (7.5%) participants met the four DSM-5 criteria for DCD and were identified as DCD (i.e. they had MABC-2 scores at or below the 5th percentile and parents reported that motor difficulties adversely affected their daily life, these had an onset in early childhood, and the child had no neurological impairment or intellectual disability). 1935 children were identified as 'non-DCD' for the study (i.e. they had MABC-2 scores above the 5th percentile)[2] who were reported by their parents not to have any neurological impairment or intellectual disability. Chi-square analyses were used for all categorical variables to test for significance in comparing the prenatal, perinatal, neonatal, environmental, and personal factors between the DCD and non-DCD groups.

3. Results

The results showed that there was a significant association between children's BMI and DCD; boys were also more likely to have DCD compared to girls (Table 4). The mothers of children with DCD were more likely to experience placenta previa, and

2 All children with a Movement ABC-2 Test score at or below the 5th percentile were diagnosed as DCD with the information from their parents; among the children with test scores above the 5th percentile, parents of 713 children also reported that their child had a motor difficulty. However, these children were considered as non-DCD in the current study with an average Movement ABC-2 Test score of 9.6 (from a distribution with a mean of 10 and SD of 3).

placental abruption during their pregnancy (Table 5). During the perinatal and neonatal period, children born prematurely (≤37 weeks) were more likely to have DCD (Table 6). For the environmental factors, children who were the only child in their family were more likely to have DCD, and parents with higher education backgrounds were more likely to have children with DCD (Table 7).

(insert Table 4 here)

(insert Table 5 here)

(insert Table 6 here)

(insert Table 7 here)

Statistically significant risk factors were entered in a three-step logistic regression model (first incorporating personal risk factors, then perinatal and neonatal risk factors, environmental risk factors were entered at last). Given the high correlation between BMI and sex, BMI and parents' education, parents' education and sibling status, and two parents' education level to each other ($p<.01$), the best fit model was then calculated (Table 8). In this model, both parents' education level (mother and father's) were combined as one variable of "parents' education", with two categories of "both parents' education length ≤12 years", and "other". In the final model, BMI, sex, and preterm birth remained significant with the addition of prenatal factors of placental abruption and placenta previa. Parents' education level was also significant. Table 7 and Figure 1 showed the odd ratio (OR), R^2 value, AUC (the area under curve) value and comparisons of ROC (receiver operating characteristics) curves for the logistic regression models.

(insert Table 8 here)

(insert Figure 1 here)

4. **Discussion**

The aim of this study was to use a national representative sample of 3-10-year-old children in China to evaluate the association of prenatal, perinatal, neonatal, and family environmental risk factors for DCD. Both sex and BMI of children were controlled for in this analysis. To our knowledge, this is the first population-based study on DCD looking at both obstetric and environmental risk factors for DCD. In our study, we used stricter criteria to define DCD (≤5% on the Movement ABC-2 Test and meeting all 4 DSM-5 diagnostic criteria for DCD), which resulted in a sample with the fewest false positives. Our findings confirmed that children with obstetric difficulties during pregnancy and born prematurely are more likely to develop DCD; family environment variables like parents' education level and one-child status are also risk factors for DCD in China independent from personal and obstetric factors.

Male sex has been confirmed with our study to be associated with DCD. With our national representative sample, boys have a much higher prevalence of DCD compared to girls (10.0% vs 4.6%); and as a risk factor, male sex remained significant in all models. The result is consistent with the previous studies on western populations (Junaid & Fellowes, 2006; Kourtessis, Psalti, & Kioumourtzoglou, 2008; Ruiz, Graupera, Gutiérrez, & Miyahara, 2003; Larsen, Mortensen, Martinussen, & Andersen, 2013) as well as East Asian populations (Chow, Hsu, Henderson, Barnett, & Lo, 2006; Kita, et al., 2016; Hirata, et al., 2018; Hua, et al., 2014a; Hua, et al., 2014b). Our result is also consistent with the sex difference reported in other developmental disorders such as dyslexia (Arnett, DeFries, & Olson, 2017), and ADHD (Sauver, et al., 2004). However, an estimate of the incidence of motor impairments by sex is unclear even with the universal consistent sex difference (Cairney, Hay, Faught, Mandigo, & Flouris, 2005). Some studies have claimed that sex differences in pre-pubescent school-aged children can be attributed more to social and environmental factors than to biological factors (Garcia, 1994). It should be noticed that there was a correlation between BMI score and male sex, with boys having a higher BMI score than girls. However, the multilevel logistic regression analysis suggested that male sex still made a significant contribution to DCD even after BMI was controlled. Therefore, the universal sex difference found across cultures and confirmed by the current study cannot rule out personal, environmental, or genetic contributions to DCD. More evidence in the future is needed from a culture with different social gender roles in childhood.

In our study, prenatal variables of placenta previa, and placental abruption differed between the DCD and non-DCD group. As previously noted, preterm birth (≤ 37 weeks) also significantly predicted DCD with our data. However, none of the other perinatal or neonatal variables reached significance in the between-group comparisons. Placenta previa and placental abruption are associated with preterm labour, and lead to a higher risk of neurological disorder (Trønnes, Wilcox, Lie, Markestad, & Moster, 2014; Furuta, Tokunaga, Furukawa, & Sameshima, 2014; Dammann & Leviton, 1997), which may induce the children's motor impairment. With our sample, the perinatal factor of low birth weight was not significantly different between the DCD and non-DCD group, which is different from Zwicker et. al.'s results (2013) from a Canadian sample but consistent with Hua et. al.'s results (2014a) from a Chinese sample; the latter study also reported preterm birth but not low birth weight as being associated with DCD. China has been reported with a lower preterm birth rate (Blencowe, et al., 2012) but generally a lower birth weight (Janssen, et al., 2007) compared to western populations. Therefore, future study might be needed to explore whether such a difference in results is culture-specific, and the different contributions from lower birth weight and preterm status on DCD needs to be distinguished.

In our study, we tested the association between family SES factors such as parents' education and family income and DCD. We also included other family environmental variables such as sibling status, main caregiver, and time spent in physical outdoor activity. Consistent with earlier results (Hua, et al., 2014b), we found one-child status was a significant predictor of DCD. However, we didn't find any significant association between family income and DCD, but only a positive association between parents' education level and DCD. In the current study, an objective assessment was used to identify children with motor difficulty; detailed instructions were given and a telephone interview to parents of children with a poor performance on the Movement ABC-2 Test was also conducted. These efforts were made to avoid the possibility that parents with a higher education level may better recognize any motor problems of their children in daily life. It should be noticed that with our sample, parents' education level was correlated to family income, children's BMI score, and one-child status of the family. Also, with our data, there was no correlation between one child status and a child's BMI score. Previous researchers interpreted the reason that one-child status is a predictor of DCD in the Chinese population might be due to the overprotection of parents of their only child (Hua, et al., 2014b; Tso, et al., 2018), and our results here provide further interpretation. A significant prediction of parents' education level on DCD as found in the current study suggests that parents with higher education levels may be more likely to have the pregnancy at a later age, and have a higher chance to have only one child, and provide more nutrition to their children. Therefore, their children are more likely to be born premature, have no daily interaction with a sibling in their family, and have a higher BMI score, resulting in a higher chance of having DCD. In a meta-analysis study conducted by Birnie et al. (2011), there was a suggestion that the association of parental education with children's motor performance was stronger than the association of either father's occupation or childhood economic environment. Therefore, our results suggested that the parenting strategy affected by different education levels of the parents may be a stronger contribution compared to the economic factors of the family environment on children's motor development.

In conclusion, our results suggested that male sex, BMI score, preterm birth, and some prenatal conditions are significant risk factors for DCD. Parents' education level and one-child status as two significant risk factors for DCD appear largely independent of male sex, BMI, or obstetric risk factors in the Chinese population. This study provides an opportunity to explore the hypothesis of mechanisms responsible for DCD and suggest potential intervention programs that could be explored in the future. When monitoring the potential cases of DCD, not only obstetric risk factors for DCD should be considered, family environment factors especially the parenting strategy on children should also be included in early screening.

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References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders.* American Psychiatric Pub.

Arnett, A. B., DeFries, J. C., & Olson, R. K. (2017). Explaining the sex difference in dyslexia. *Journal of Child Psychology and Psychiatry*, 58(6), 719-727.

Birnie, K., Cooper, R., Martin, R., Kuh, D., Sayer, A., Alvarado, B., . . . Corley, J. (2011). Childhood socioeconomic position and objectively measured physical capability levels in adulthood: a systematic review and meta-analysis. *PloS One*, 6(1), e15564.

Blank, R. B., Rosenblum, S., Smits-Engelsman, B., Sugden, D., Wilson, P., & Vinçon, S. (2019). International clinical practice recommendations on the definition, diagnosis, assessment, intervention, and psychosocial aspects of developmental coordination disorder. *Developmental Medicine & Child Neurology*, 61(3), 242-285.

Blencowe, H., Cousens, S., Oestergaard, M., Chou, D., Moller, A., Narwal, R., . . . Lawn, J. (2012). National, regional, and worldwide estimates of preterm birth rates in the year 2010 with time trends since 1990 for selected countries: a systematic analysis and implications. *The lancet*, 379(9832), 2162-2172.

Cairney, Hay, J. A., Faught, B. E., & Hawes, R. (2005). Developmental coordination disorder and overweight and obesity in children aged 9–14 y. *International journal of obesity*, 29(4), 369-372.

Cairney, J., Hay, J., Faught, B., Mandigo, J., & Flouris, A. (2005). Developmental coordination disorder, self-efficacy toward physical activity, and play: Does gender matter? *Adapted Physical Activity Quarterly*, 22(1), 67-82.

Central Intelligence Agency. (2018, 11 28). Retrieved from The World Factbook: www.cia.gov.

Chow, S. M., Henderson, S. E., & Barnett, A. L. (2001). The Movement Assessment Battery for Children: A comparison of 4-year-old to 6-year-old children from Hong Kong and the United States. *The American Journal of Occupational Therapy*, 55(1), 55-61.

Chow, S. M., Hsu, Y. W., Henderson, S. E., Barnett, A. L., & Lo, S. K. (2006). The movement ABC: A cross-cultural comparison of preschool children from Hong Kong, Taiwan, and the USA. *Adapted physical activity quarterly*, 23(1), 31-48.

Cohen, K. E., Morgan, P. J., Plotnikoff, R. C., Callister, R., & Lubans, D. R. (2014). Fundamental movement skills and physical activity among children living in low-income communities: a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity*, 11(1), 49.

Cooke, R. W. (2005). Perinatal and postnatal factors in very preterm infants and subsequent cognitive and motor abilities. *Archives of Disease in Childhood-Fetal and Neonatal Edition*, 90(1), F60-F63.
Davis, N. M., Ford, G. W., Anderson, P. J., Doyle, L. W., & Group., V. I. (2007). Developmental coordination disorder at 8 years of age in a regional cohort of extremely-low-birthweight or very preterm infants. *Developmental Medicine & Child Neurology*, 49(5), 325-330.
Engel-Yeger, B., Rosenblum, S., & Josman, N. (2010). Movement Assessment Battery for Children (M-ABC): establishing construct validity for Israeli children. *Research in Developmental Disabilities*, 31(1), 87-96.
Freitas, T. C., Gabbard, C., Caçola, P., Montebelo, M. I., & Santos, D. C. (2013). Family socioeconomic status and the provision of motor affordances in the hom. *Brazilian journal of physical therapy*, 17(4), 319-327.
Freitas, T. C., Gabbard, C., Caçola, P., Montebelo, M. I., & Santos, D. C. (2013). Family socioeconomic status and the provision of motor affordances in the home. *Brazilian journal of physical therapy*, 17(4), 319-327.
Garcia, C. (1994). Gender differences in young children's interactions when learning fundamental motor skills. *Research Quarterly for Exercise and Sport*, 65(3), 213-225.
Giles-Corti, B., & Donovan, R. J. (2002). Socioeconomic status differences in recreational physical activity levels and real and perceived access to a supportive physical environment. *Preventive medicine*, 35(6), 601-611.
Gomez, A., & Sirigu, A. (2015). Developmental coordination disorder: core sensori-motor deficits, neurobiology and etiology. *Neuropsychologia*, 79, 272-287.
Goyen, T. A., & Lui, K. (2009). Developmental coordination disorder in "apparently normal" schoolchildren born extremely preterm. *Archives of disease in childhood*, 94(4), 298-302.
Green, D., Lingam, R., Mattocks, C., Riddoch, C., Ness, A., & Emond, A. (2011). The risk of reduced physical activity in children with probable developmental coordination disorder: A prospective longitudinal study. *Research in developmental disabilities*, 32(4), 1332-1342.
Henderson, S., Sugden, D. A., & Barnett, A. L. (2007). *Movement assessment battery for children-2 second edition [Movement ABC-2].* London, UK: The Psychological Corporation.
Hendrix, C. G., Prins, M. R., & Dekkers, H. (2014). Developmental coordination disorder and overweight and obesity in children: a systematic review. *Obesity Reviews*, 15(5), 408-423.
Hirata, S., Kita, Y., Yasunaga, M., Suzuki, K., Okumura, Y., Okuzumi, H., . . . Nakai, A. (2018). Applicability of the Movement Assessment Battery for Children-(MABC-2) for Japanese children aged 3–6 years: a preliminary investigation emphasizing internal consistency and factorial validity. *Frontiers in psychology*, 9.
Holsti, L., Grunau, R. V., & Whitfield, M. F. (2002). Developmental coordination disorder in extremely low birth weight children at nine years. *Journal of Developmental & Behavioral Pediatrics,*, 23(1), 9-15.
Hua, J., Gu, G., Jiang, P., Zhang, L., Z. L., & Meng, W. (2014a). The prenatal, perinatal and neonatal risk factors for children's developmental coordination disorder: a population study in mainland China. *Research in developmental disabilities*, 35(3), 619-625.

Hua, J., Gu, G., Meng, W., & Wu, Z. (2013). Age band 1 of the Movement Assessment Battery for Children: Exploring its usefulness in mainland China. *Research in Developmental Disabilities*, 34(2), 801-808.

Hua, J., Jin, H., Gu, G., Liu, M., Zhang, L., & & Wu, Z. (2014b). The influence of Chinese one-child family status on Developmental Coordination Disorder status. *Research in developmental disabilities*, 35(11), 3089-3095.

Humbert, M. L., Chad, K. E., Spink, K. S., Muhajarine, N., Anderson, K. D., Bruner, M. W., & Gryba, C. R. (2006). Factors that influence physical activity participation among high-and low-SES youth. *Qualitative health research*, 16(4), 467-483.

Janssen, P. A., Thiessen, P., Klein, M. C., Whitfield, M. F., MacNab, Y. C., & Cullis-Kuhl, S. C. (2007). Standards for the measurement of birth weight, length and head circumference at term in neonates of European, Chinese and South Asian ancestry. *Open Medicine*, 1(2), e74.

Junaid, K. A., & Fellowes, S. (2006). Gender differences in the attainment of motor skills on the movement assessment battery for children. *Physical & Occupational Therapy in Pediatrics*, 26(1-2), 5-11.

Kita, Y., Suzuki, K., Hirata, S., Sakihara, K., Inagaki, M., & & Nakai, A. (2016). Applicability of the Movement Assessment Battery for Children-to Japanese children: A study of the Age Band 2. *Brain and Development*, 38(8), 706-713.

Kourtessis, T. T., Psalti, M., & Kioumourtzoglou, E. (2008). Developmental coordination disorder in early childhood-A preliminary epidemiological study in greek schools. *The International Journal of Medicine*, 1(2), 9.

Larsen, R. F., Mortensen, L. H., Martinussen, T., & Andersen, A. M. (2013). Determinants of developmental coordination disorder in 7-year-old children: a study of children in the Danish N ational Birth Cohort. *Developmental Medicine & Child Neurology*, 55(11), 1016-1022.

Ruiz, L. M., Graupera, J. L., Gutiérrez, M., & Miyahara, M. (2003). The Assessment of Motor Coordination in Children with the Movement ABC test: A Comparative Study among Japan, USA and Spain. *International Journal of Applied Sports Sciences*, 15(1), 1-22.

Sauver, J. L., Barbaresi, W. J., Katusic, S. K., Colligan, R. C., Weaver, A. L., & Jacobsen, S. J. (2004). Early life risk factors for attention-deficit/hyperactivity disorder: a population-based cohort study. *Mayo Clinic Proceedings*, 79(9), 1124-1131.

Shah, P. S. (2010). Parity and low birth weight and preterm birth: a systematic review and meta-analyses. *Acta obstetricia et gynecologica Scandinavica*, 89(7), 862-875.

Tso, W. W., B., Li, M., Xu, X., Ao, L., Zhang, X., . . . Shang, X. (2018). The Griffiths Development Scales-Chinese (GDS-C): A cross-cultural comparison of developmental trajectories between Chinese and British children. *Child: care, health and development*, 44(3), 378-383.

Venetsanou, F., & Kambas, A. (2010). Environmental factors affecting preschoolers' motor development. *Early childhood education journal*, 37(4), 319-327.

Wilmut, K., Du, W., & Barnett, A. L. (2015). How do i fit through that gap? Navigation through apertures in adults with and without developmental coordination disorder. *PloS one*, 10(4).

Wuang, Y. P., Su, J. H., & Su, C. Y. (2012). Reliability and responsiveness of the Movement Assessment Battery for Children–Second Edition Test in children with developmental coordination disorder. *Developmental Medicine & Child Neurology*, 54(2), 160-165.

Zwicker, J. G., Missiuna, C., Harris, S. R., & Boyd, L. A. (2012). Developmental coordination disorder: a review and update. *European Journal of Paediatric Neurology*, 16(6), 573-581.

Zwicker, J. G., Yoon, S. W., MacKay, M., Petrie-Thomas, J., Rogers, M., & Synnes, A. R. (2013). Perinatal and neonatal predictors of developmental coordination disorder in very low birthweight children. *Archives of disease in childhood*, 98(2), 118-122.

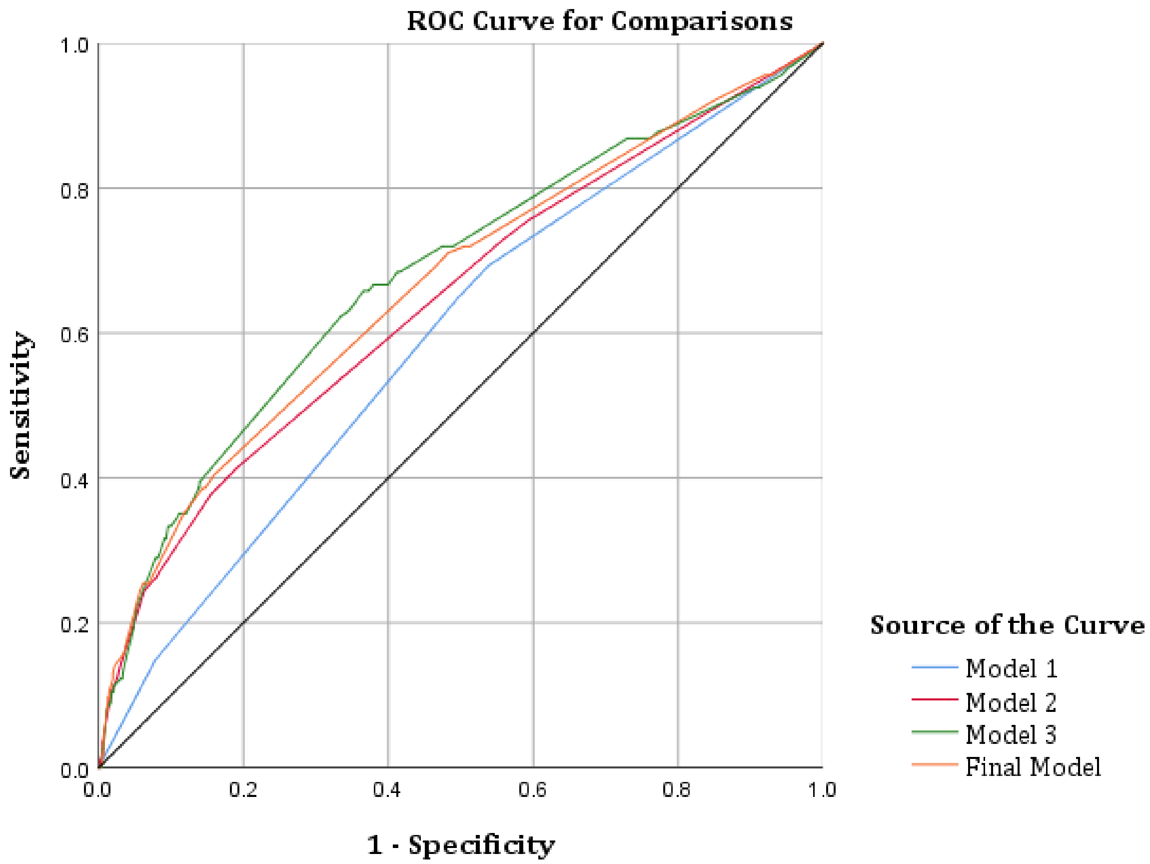

Figure 1 The comparisons of ROC curves for the logistic regression models

Table 1 The number of children targeted and actually recruited in each region

	Actual sample		Targeted (according to the 2010 Census)	
	N	%	N	%
Northeast China	179	8.2%	170	8.5%
North China	367	16.8%	258	12.9%
East China	701	32.1%	662	33.1%
South China	335	15.3%	325	16.3%
Southwest China	197	9.0%	185	9.2%
Northeast China	141	6.5%	126	6.3%
Central China	265	12.1%	274	13.7%
Total	2185		2000	

Table 2 The number of children actually recruited in each age and Sex group

Age group (year)	Boy	Girl	Total
3	96	107	203
3.5	124	109	233
4	118	111	229
4.5	118	107	225
5	123	114	237
6	105	98	203
7	118	103	221
8	113	99	212
9	116	100	216
10	112	94	206
Total	**1143**	**1042**	**2185**

Table 3 Average length of education of parents[3]

Length of education years of parents	**Mother**		**Father**	
	N	%	N	%
<9 years	172	8.8	147	7.5
9-12	374	19.2	350	17.9
12-16	1047	53.6	1081	55.3
>17 years	360	18.4	378	19.3
Total	1953		1956	

3 For 229 children information on the parents' education was missing, leaving data for 1956. The missing data was considered to be random and therefore should not affect the sample or the results.

Table 4 Numbers for BMI and Sex in the DCD and non-DCD groups.

	DCD(%)	Non-DCD(%)	X^2	*p*
BMI(>18)	19.2	11.9	7.08	.008**
Sex			21.38	<.001***
Girls	30.1	49.4		
Boys	69.9	50.6		

**p<.01; ***p<.001.

Table 5 The prenatal risk factors for the DCD and non-DCD groups.

Risk factors	DCD(%)	Non-DCD(%)	X^2	*p*
Maternity age (>35y/o)	3.6	7.3	2.62	.11
Maternal smoking	0.0	1.2	1.68	.20
Maternity obesity (BMI>25)	12.1	10.7	0.28	.60
Placenta previa	10.9	3.8	14.73	<.001***
Placental abruption	2.3	0.5	5.66	.02*
Eclampsia	0.8	0.1	5.47	.14
Preeclampsia	0.7	0.2	1.20	.32
Gestational diabetes	4.4	4.7	0.04	.85
Pregnancy hypertension	2.2	2.4	0.03	.87
Pregnancy anemia	8.0	9.9	0.49	.48
Pregnancy hyperthyroidism	0.7	0.2	1.21	.32
Pregnancy hypothyroidism	2.3	1.6	0.34	.56
Placental adhesion	0.7	0.3	0.77	.37

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

Table 6 The perinatal and neonatal risk factors for the DCD and non-DCD groups.

Risk factors	DCD(%)	Non-DCD(%)	X^2	*p*
Preterm birth (≤37 weeks)	18.0	8.7	11.99	.001**
Low birth weight (<2000g)	3.2	1.4	2.87	.09
Delivery type			0.69	.41
Normal delivery (incl. assisted)	43.9	47.5		
Caesarean section	56.1	52.5		
Newborn pathological jaundice	16.8	12.0	1.90	.17
Perinatal hypoxia	0.0	0.6	0.60	.44
Chronic lung disease	1.1	2.2	0.58	.45
Infection	0.0	0.6	0.60	.44
Postpartum depression	1.4	3.0	1.15	.29

**p<.01.

Table 7 The environmental risk factors for the DCD and non-DCD groups.

Risk factors	DCD(%)	Non-DCD(%)	X^2	*p*
Mothers' education length			4.71	.03*
≤12	20.3	28.9		
>12	79.7	71.1		
Fathers' education length			4.74	.03*
≤12	17.6	26.1		
>12	82.4	73.9		
Family annual income			0.52	.47
≤CNY12k	38.3	41.7		
>CNY12k	61.7	58.3		
Sibling status				
Only child	79.1	67.9	7.57	.006**
Outdoor physical activity hours/week			2.54	.28
≤2hours/week	15.8	11.6		
2-8hours/week	49.6	49.8		
>8hours/week	34.5	38.6		
Main caregiver			2.05	.15
Parents	82.7	87.0		
Grandparents &others	17.3	13.0		

*p<.05; **p<.01.

Table 8 the comparisons of logistic regression models of DCD

	Model	B	Wald χ^2	*p*	OR (95% CI)	R^2	AUC
1	BMI (>18)	-0.46	4.40	0.04*	0.63(0.41-0.97)	0.03	.61
	Sex Male	-0.77	18.34	<0.001***	0.46(0.32-0.66)		
2	BMI (>18)	-0.43	2.88	0.09	0.65(0.39-1.07)	0.06	.65
	Sex Male	-0.63	9.35	0.002***	0.53(0.36-0.80)		
	Placenta previa	-1.34	15.84	<0.001***	0.26(0.14-0.51)		
	Placental abruption	-1.68	5.41	0.02*	0.19(0.05-0.77)		
	Preterm birth	-0.72	7.38	0.007*	0.49(0.29-0.82)		
3	BMI (>18)	-0.52	3.91	0.048*	0.60(0.36-0.99)	0.07	.68
	Sex Male	-0.60	8.30	0.004***	0.55(0.37-0.83)		
	Placenta previa	-1.39	16.73	<0.001***	0.25(0.13-0.48)		
	Placental abruption	-1.69	5.44	0.02*	0.19(0.05-0.76)		
	Preterm birth	-0.71	6.74	0.009**	0.49(0.29-0.84)		
	Mother's education length	0.28	0.75	0.39	1.33(0.70-2.54)		
	Father's education length	0.24	0.53	0.47	1.27(0.66-2.45)		
	Sibling status	-0.39	2.63	0.10	0.68(0.42-1.09)		
Final model	BMI(>18)	-0.53	4.16	0.04*	0.59(0.36-0.98)	0.07	.67
	Sex Male	-0.59	8.18	0.004**	0.55(0.37-0.83)		
	Placenta previa	-1.38	16.50	<0.001***	0.25(0.13-0.49)		
	Placental abruption	-1.64	5.21	0.02*	0.19(0.05-0.79)		
	Preterm Birth	-0.72	6.99	0.008**	0.49(0.28-0.83)		
	Parents' education	-0.72	5.80	0.02*	0.49(0.27-0.88)		

*p<.05; **p<.01; ***p<.001.