Developmental Coordination Disorder and the risk of overweight and obesity: A systematic review.

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Abstract

Background: Developmental coordination disorder (DCD) is a neuro-developmental disorder that is characterized by fine and/or gross motor coordination problems that are not the result of any neurological condition or intellectual disability and interfere significantly with academic achievement or activities of daily living. Children with DCD find themselves to be less competent than typically developing (TD) children with regard to their physical abilities, often experience failure and have a higher risk of sustaining injuries. As a result, children with DCD are more likely to avoid participation in physical activities. Physical inactivity is considered to be an important risk factor for developing overweight and obesity.
Objective: The aim of this systematic review was to assess whether children with DCD are at greater risk of developing overweight and obesity than their TD peers, and whether sex and age are predictor variables.
Method: Six major electronic databases were systematically searched to identify studies containing data on body composition in children with DCD. Acceptable outcome measures included BMI(weight to height), body fat (in mass or percentage), and waist circumference. Acceptable DCD assessment tools were MABC, MABC-2, BOTMP and BOTMP-SF. The title and abstract of all studies from the search were judged for relevance. Remaining studies were subjected to full paper review. The quality of included papers was assessed and relevant data were extracted for comparison.
Results: The search yielded 180 results, of which 14 studies were included. All were observational studies, made up of cross-sectional designs (n=11) and prospective cohorts (n=3). Participants' ages ranged from 4 to 14 years(y). Only 3 studies contained children below 9y and only 1 of these included children under 6. All studies reported that children with DCD had higher BMI scores, larger waist circumference (WC) and greater percentage body fat compared to controls. Between group differences were found significant for one or more outcome measures by 12 studies. Gender effects were assessed by 8 studies and 7 found no significant difference. The effect of age was assessed by several studies containing only children $\geq$ 9y and was not found significant. 1 study found no significant difference for children aged 4 to 9y, but did for 10 to 12 year olds.
Conclusion: Children with DCD are likely to be at greater risk for both overweight and obesity, regardless of gender. This increased risk may not become apparent before a certain age, however more research is needed to confirm this.

Developmental Coordination Disorder and the risk of overweight and obesity: A systematic review.

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Introduction

Developmental coordination disorder (DCD) is described in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) as a neuro-developmental disorder that is characterized by poor fine and/or gross motor coordination. These coordination problems are not the result of a neurological condition or intellectual disability. In order for a diagnosis to be made, the problems with motor coordination must significantly interfere with academic achievement or activities of daily living (ADL) (American Psychiatric Association, 2000). The DSM-IV criteria for DCD are presented in

table 1. Depending on how stringently these criteria are applied, the prevalence of DCD is estimated to range from 1,7% to 6%, and, in boys is found four to seven times more often than in girls (American Psychiatric Association 2000; Gibbs, Appleton, & Appleton, 2007; Kadesjo & Gillberg, 1999; Lingam, et al., 2009. DCD is a chronic disorder that continues into adulthood (Barnhart, et al., 2003).

The primary cause of DCD is not known; although literature has provided several theories over the years, none of which could be proven. Dyspraxia (planning execution of motor tasks), problems with the execution itself, proprioception, sensory integration and visual processing have all been theorized as possible causative factors. (Smyth & Mason, 1997; Smyth &Mason, 1998; Wilson & McKenzie, 1998; Sigmundsson, et al., 2003) The difference in theories may be explained by the fact that the group of children with DCD is a heterogeneous group, therefore each theory may explain the problems of different children in this population (Taft & Barowsky, 1989; Smyth, 1992; Willoughby & Polatajko, 1995). Lichtenstein (2010) found that DCD may have a genetic component, and also perinatal oxygen perfusion problems are associated with the disorder (Pearsall-Jones, et al., 2009).

Children with DCD find themselves to be less competent than typically developing children with regard to their physical abilities, but also psychologically and socially (Cairney, et al., 2000; Lloyd, et al., 2006). Also, children with DCD find it very difficult to learn new skills, often experience failure and have a higher risk of sustaining injuries. Together, this makes that children with DCD are more likely to avoid participation in physical activities (Bouffard, et al., 1996; Hands & Larkin, 2002; Cairney, et al., 2005; Lloyd, et al., 2006). Along with unhealthy dietary habits, physical inactivity is an important risk factor for developing overweight and obesity (Tremblay & Willms, 2000; Faith, et al., 2001; Jolliffe, 2004; World Health Organization, 2009).

Overweight and obesity have become an increasing problem in the past decades. The World Health Organization (WHO) (2008, 2009) has stated that the prevalence of overweight and obesity among children ranges from 5% to 25% in the European region alone, and up to 30% in the whole western world, and is still increasing rapidly. It seems that overweight and obesity in youth is an important predictor of overweight and obesity in adulthood (Biddle, et al., 2004). In adults, obesity is associated with a range of cardiovascular diseases (i.e. hypertension, hyperlipidaemia, ischemic stroke, coronary heart disease, type 2 diabetes), osteoporosis and psychosocial problems (Freedman et al., 2007; Imperatore, 2006; Malecka-Tendera & Mazur, 2006; WHO, 2009).

Cairney (2009) found that the activity deficit among children with DCD does not diminish over time and their results indicate that it persists into adulthood. Therefore, children with DCD would seem to be at a higher risk of developing overweight or obesity. Only a few studies have looked directly at DCD as a risk factor for overweight or obesity (Cairney, et al., 2005; Cairney, et al., 2010; Cairney, et al., 2011). Several other studies, most of which were aimed at physical activity or fitness in children with DCD, included body composition as a measurement(Faught, et al., 2005; Tsiotra, et al., 2006; Schott, et al., 2007; Cantell, et al., 2008; Tsiotra, et al., 2009; Wu, et al., 2010; Li, et al., 2011; Wahi, et al., 2011; Fong, et al., 2011; Chirico, et al., 2011; Chirico, et al., 2012). The evidence found, consists of cross-sectional and longitudinal cohort studies. No systematic reviews have yet been published that directly studied the question whether children with DCD are at a greater risk of developing overweight and obesity than their typically developing peers. This will be the main aim of this review, complemented by the question whether age and sex are also predictor variables.

A systematic review of the literature can give a deeper insight in the available evidence and its quality, and is valuable in understanding the problems that go along with DCD. This in turn could contribute to a full and complete treatment of the disorder and prevention of potentially negative aspects thereof.

Table 1. ***DSM-IV diagnostic criteria for DCD***

A. *Performance in daily activities that require motor coordination is substantially below that expected given the person's chronologic age and measured intelligence*
B. *The poor motor performance significantly interferes with academic achievement or activities of daily living (ADL)*
C. *The disturbance is not due to a general medical condition (e.g., cerebral palsy, hemiplegia, muscular dystrophy)*
D. *If intellectual disability (i.e. mental retardation) is present, the motor difficulties are in excess of those usually associated with it*

Method

Search strategy

The literature was systematically reviewed to identify studies containing measurements of body composition in children with DCD. A search strategy was adopted that combined two groups of terms, namely (1) Developmental Coordination Disorder and (2) body composition. DCD is the preferred term to describe problems with motor coordination in children. However, different terms have been used in the past, and, in some places are still in use. (Magalhães, et al., 2006). To make sure that all possible studies on the subject were found, the first group consisted of a range of different terms concerning motor coordination and problems therewith, including: developmental coordination disorder, developmental dyspraxia, motor skills disorder, coordination disorder, incoordination, clumsy, motor proficiency, motor competence, motor difficulties, motor impairment, motor coordination. The purpose of the second group of terms was to capture all possible outcome measurements of body composition. These terms included: overweight, obesity, body composition, body mass index (BMI), body fat, adiposity. Studies were only included if the title and abstract contained at least one term from each group (example in table 2).

A systematic search was performed in the following six databases: Pubmed, Cochrane Library, Cinahl, Academic Search Premier, Science Direct, and Pedro. In this search, no limits were set for date of publication of studies. All articles found were judged for relevance, based on the title and abstract. To make sure that no studies were left out of the search, the reference lists of the articles that met inclusion criteria were screened for any relevant studies that may not have been captured by the search of the databases. All articles that seemed relevant were then subjected to a full paper review.

Table 2. ***Example of Pubmed search***

((((((((((("overweight"[Title/Abstract]) OR "obesity"[Title/Abstract]) OR "body composition"[Title/Abstract]) OR "coordination disorder"[Title/Abstract]) OR "incoordination"[Title/Abstract]) OR "Clumsy"[Title/Abstract]) OR "Motor proficiency"[Title/Abstract]) OR "Motor competence"[Title/Abstract]) OR "Motor difficulties"[Title/Abstract]) OR "Motor impairment"[Title/Abstract]) OR "Motor coordination"[Title/Abstract]) AND ((((((("overweight"[Title/Abstract]) OR "obesity"[Title/Abstract]) OR "body composition"[Title/Abstract]) OR "Body mass index"[Title/Abstract]) OR "bmi"[Title/Abstract]) OR "Body fat"[Title/Abstract]) OR "Adiposity"[Title/Abstract])

Inclusion and exclusion criteria

All articles in which body composition was measured in a group of children and/or adolescents with DCD, with or without comparison to typically developing peers, were included. Articles that tested for DCD in a group of overweight and/or obese children were not included in the review. If only part of the participants in a study met the inclusion criteria, data of that part alone was extracted for analysis if possible. If, in such a case, it was not possible to discriminate between participants that did and did not meet inclusion criteria, the study was excluded from the review.

Body composition

Measurements of body composition include: BMI(weight to height), body fat (in mass or percentage), and waist circumference.

DCD

In research, it is not uncommon to find that not all of the DSM IV criteria are met. One often finds DCD to be described as 'probable DCD' (pDCD) because of these limitations. Therefore, articles were not required to meet all the DSM IV criteria in order to be included. DCD or pDCD were assumed if participants met at least criterion A of the DSM IV. Criterion A is seen as the most important because it requires the motor coordination to be assessed. The Movement Assessment Battery for Children 1st editon(MABC) or 2nd editon (MABC-2) (Henderson & Sugden, 1992; Henderson & Sugden, 2007), or the long or short form of the Bruijninks-Oseretsky Test for Motor Proficiency (BOTMP) (BOTMP-SF) (Bruininks, 1978) had to have been used to identify DCD or pDCD. The MABC, MABC-2 and the BOTMP and BOTMP-SF are the most commonly used tests to identify DCD in children (Crawford et al., 2001; Miller, et al., 2001). Both the MABC(1st and 2nd edition)and the BOTMP and BOTMP-SF have been found to have a good reliability and validity (Crawford, et al., 2001; Tan, et al., 2001; Henderson, et al., 2007).

The MABC and MABC-2 are two versions of an individually administered test that assesses motor impairment. It consists of eight testing items and has three subscales measuring manual dexterity, ball skills and balance. The MABC is divided into four age bands for children in the age of 4 to 12 years old. The MABC-2 is divided into three age bands for children in the age of 3 to 16 years old.

The BOTMP is an individually administered test that assesses motor proficiency of children in the age of 4.5 to 14.5 years old. The assessed parameters include running speed and agility, balance, bilateral coordination, strength, upper limb coordination and dexterity, and response speed. In research, the BOTMP-SF is often used instead of the full version. The short form consists of only 14 of the 46 items in the original version, increasing its feasibility.

A cut off point used for applying Criterion A varies widely among different studies. The 2006 Leeds consensus statement on DCD recommends the cut off point to be applied to performance at or below the 5th percentile (Sugden, 2006). At the same time it is recognized that the 5th percentile is arbitrary and it is also recommended to monitor children scoring at or below the 15th percentile. Articles written before 2006 are likely to not have used the 5th percentile as a cut off point and many different percentile rates are still used in literature. Therefore no limits were set for the percentile rate used in the articles.

Methodological quality assessment

Because methodological quality is open to different interpretations in observational studies, it should be noted that in this review it is regarded as 'susceptibility to bias'. The articles included in this review consisted of longitudinal cohort studies and cross-sectional studies, and thus were all observational in nature. As no gold standard currently exists for assessing the methodological quality of observational studies, objective measurement of that quality is impossible. However, guidelines now do exist on the reporting of observational studies (Strengthening the Reporting of Observational Epidemiological studies – STROBE), but these guidelines have been regularly misused in systematic reviews of such studies as a quality assessment tool (da Costa, et al., 2011). Although a gold standard

is lacking, many different tools for appraisal of the quality of observational studies have been created and used in systematic reviews (Mallen et al, 2006; Sanderson et al, 2007).
Mallen (2006) and Sanderson (2007) both found that a consensus on what items should be included in quality assessment tools of observational studies, has clearly not yet been reached and no single tool was found to be adequate for generic use. However, they both did find a number of criteria, used in these tools, that represent the principal potential sources of bias and were generally considered to be important. These criteria include: appropriate selection of case/controls, use of accurate and appropriate outcome measures in all participants, appropriate statistical analysis, adjustment for confounding, and assessment of loss to follow-up. All studies included in this review were subjectively appraised on these five criteria. For each criterion several questions were formulated that could be answered with 'yes', 'no', 'unknown' or 'not applicable'. This resulted in a list of 11 questions on which the included studies were screened by the author(table 3).

Table 3. ***Subjective assessment of quality***

Appropriate selection of case/controls
1)Was there a clear description of the characteristics of participants?
2)Were participants representative of the population?
3)Was any information provided on the possibility of selection bias?

Use of accurate and appropriate outcome measures in all participants
4)Was there a clear description of the outcomes to be measured in the study?
The outcomes of the study were to be mentioned in the introduction and/or method section for this question to be answered with a 'yes'.
5)Were the outcome measures used in the study valid and reliable?
In order for this question to answered with a 'yes', the outcome measures had to have been described clearly. If it was not described, a referral to other work that establishes accuracy was found sufficient for a 'yes'.

Appropriate statistical analysis
6)Were all statistical methods described clearly?
7)Were the statistics used in the study appropriate for the main outcomes?

Adjustment for confounding
8)Have all important confounders (in/among the groups of participants) been clearly described?
9)Was it made clear which confounders were adjusted for in the analyses and why?

Assessment of loss to follow-up
10)Were losses of participants to follow-up reported?
11)Were these losses to follow-up taken into account?
Obviously, if question 10 is answered with 'no', 'unknown' or 'not applicable', question 11 will subsequently be answered with 'not applicable'.

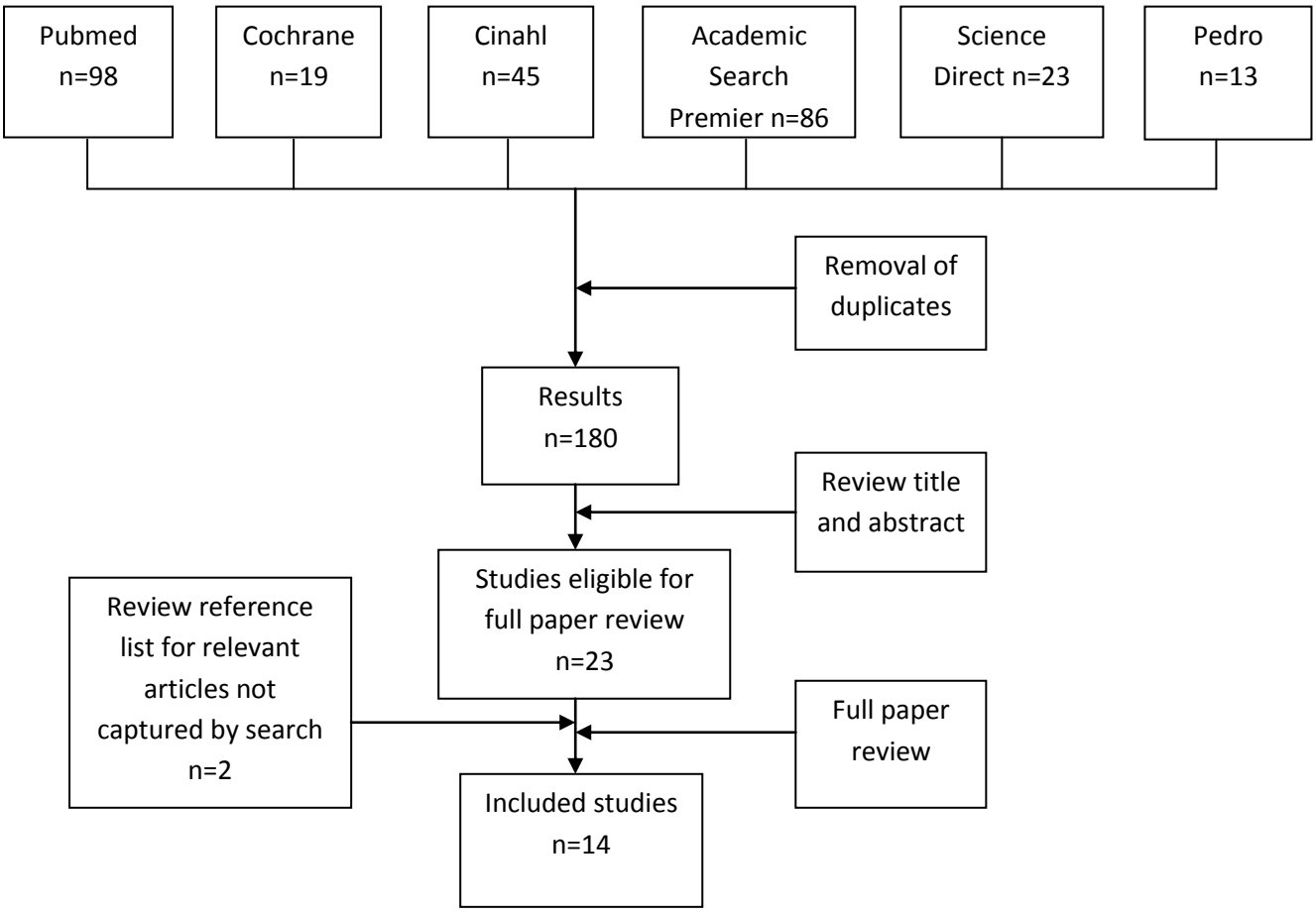
Data extraction
Relevant data were extracted for comparison. Data that were extracted from the articles included: Author, year of publication, study design, population (sample size, age, sex), DCD assessment tool and the percentile rate(s) used, outcome measure(s), outcomes/results, conclusion(s) made in the

article(when relevant), and any relevant study limitations. These were then summarized(see results) and compared by the author.

Results

The search yielded a total of 284 articles. After removing duplicates, 180 articles remained. All 180 articles were reviewed for relevancy by the author, based on title and abstract. 23 studies were found to be eligible for full paper review. A manual review of the reference lists yielded another 2 studies, relevant for full paper review. Of the 25 studies that were subjected to full paper review, 14 met inclusion criteria. A flowchart of the selection process is presented in table 4.

Table 4. ***Flowchart of selection process***



Quality assessment

The results of the quality as assessed by the author are presented in table 5. All studies gave a clear description of the selection of participants, whereas only a few provided information on the possibility of selection bias. Outcome measures and their reliability and validity were clearly described by all but 1 article. This was also the only article in which it was unclear whether the used statistics were appropriate for the main outcomes. Except for 1 article, all described the statistical methods clearly. The majority of the articles described potential confounders and adjusted for these in the statistical analyses, 4 articles however did neither. Of the 3 longitudinal studies, only 1 reported on losses to follow-up but it remained unclear whether this was taken into account.

As this was a subjective assessment, any assumptions based on this assessment should be treated with caution.

Table 5. ***Quality assessment outcomes***

Question / Author	1	2	3	4	5	6	7	8	9	10	11
Cairney (2005)[C]	Y	Y	N	Y	Y	Y	Y	Y	Y	NA	NA
Cairney (2010)[L]	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	NA
Cairney (2011)[C]	Y	Y	N	Y	Y	Y	Y	Y	Y	NA	NA
Wahi (2011)[C]	Y	Y	N	Y	Y	Y	Y	N	N	NA	NA
Faught (2005)[C]	Y	Y	N	Y	Y	Y	Y	Y	Y	NA	NA
Tsiotra (2006)[C]	Y	Y	N	Y	Y	Y	Y	N	N	NA	NA
Schott (2007)[C]	Y	Y	N	Y	Y	Y	Y	Y	Y	NA	NA
Cantell (2008)[C]	Y	U	N	Y	Y	Y	Y	Y	Y	NA	NA
Tsiotra (2009)[C]	Y	Y	N	Y	Y	Y	Y	Y	Y	NA	NA
Wu (2010)[C]	Y	Y	Y	Y	Y	N	Y	N	N	NA	NA
Fong (2011)[C]	Y	U	Y	Y	Y	Y	Y	Y	Y	NA	NA
Li (2011)[L]	Y	Y	N	N	U	Y	U	N	N	Y	U
Chirico (2011)[C]	Y	Y	N	Y	Y	Y	Y	Y	Y	NA	NA
Chirico (2012)[L]	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	NA

Y=yes, N=no, U=unknown, NA=not applicable, C=cross-sectional, L=longtitudinal

Study characteristics

The data that were extracted are summarized in table 6. Of the 14 studies included in this review, 11 used cross-sectional study designs and 3 were longitudinal studies. The longitudinal studies were all prospective cohorts, two of which had a follow up duration of 3 years and one had a follow up duration of 2 years. In the included studies, sizes of the samples of children with pDCD ranged from 12 to 123. Ages of participants ranged from 4 to 14 years. Only 3 studies contained children below the age of 9 and only 1 study contained children under 6 years of age. All studies used control groups for comparison, frequently described as typically developing (TD) children. The MABC, MABC-2 or BOTMP-SF were used by most studies to identify children with pDCD. One study used the BOTMP and this was also the only study to make a formal diagnosis of DCD (i.e. meeting all DSM-IV criteria). Cut off points used in the studies to identify children as having DCD or pDCD (i.e. applying DSM-IV criterion A) ranged from the 5^{th} to the 15^{th} percentile. Two studies divided the group of children with pDCD into two subgroups. The first group consisted of children scoring at or below the 5^{th} percentile. The second group consisted of children scoring between the 6^{th} and the 15^{th} percentile. One of these two studies also divided the group of TD children into two subgroups scoring either between the 16^{th} and the 50^{th} percentile or above the 50^{th} percentile. The outcome measures used to assess body composition included BMI, body fat (in % or kg) and waist circumference. BMI was used in all but 3 studies and 7 studies used a combination of two measures.

Data synthesis

All of the 14 studies included in this review reported that children with DCD or pDCD had higher BMI scores, larger waist circumference (WC) and greater percentage body fat compared to their TD peers

(DCD-). 12 Studies found differences between groups to be statistically significant for one or more of these outcome measures(Cairney, et al., 2005; Cairney, et al., 2010; Cairney, et al., 2011; Wahi, et al., 2011; Faught, et al., 2005; Tsiotra, et al., 2006; Schott, et al., 2007; Cantell, et al., 2008; Tsiotra, et al., 2009; Fong, et al., 2011; Chirico, et al., 2011; Chirico, et al., 2012).
Of the 11 studies using BMI as an outcome measure(Cairney, et al., 2005; Cairney, et al., 2010; Cairney, et al., 2011; Schott, et al., 2007; Cantell, et al., 2008; Tsiotra, et al., 2009; Wu, et al., 2010; Fong, et al., 2011; Li, et al., 2011; Chirico, et al., 2011; Chirico, et al., 2012), 8 studies found the differences between groups to be significant(Cairney, et al., 2010; Cairney, et al., 2011; Schott, et al., 2007; Cantell, et al., 2008; Tsiotra, et al., 2009; Fong, et al., 2011; Chirico, et al., 2011; Chirico, et al., 2012).
Body fat was measured in 8 Studies (Cairney, et al., 2005; Cairney, et al., 2011; Faught, et al., 2005; Tsiotra, et al., 2006; Wu, et al., 2010; Li, et al., 2011; Chirico, et al., 2011; Chirico, et al., 2012), 6 of which found the difference to be significant(Cairney, et al., 2005; Cairney, et al., 2011; Faught, et al., 2005; Tsiotra, et al., 2006; Chirico, et al., 2011; Chirico, et al., 2012). WC was used as an outcome measure in only 2 studies (Cairney, et al., 2010; Wahi, et al., 2011). Both found children with pDCD to have significantly greater WC than their TD peers.

Percentile rate
6 Studies contained groups for which the 5th percentile was the cut-off point for DCD. 2 Of these studies found the differences in body composition between groups to be significant(Cairney, et al., 2010; Cairney, et al., 2011). Wu (2010) and Li (2011) found the differences not to be significant but both did show a trend. 1 Study reported the difference between groups to be significant when using body fat as a measure and showed a non significant trend when using BMI(Cairney, et al., 2005). Schott (2007) found significant differences, but only for children over 9 years of age.

Overweight and obesity
Several studies used the measurements to identify children being overweight and/or obese. Cairney (2005) reported 23% of DCD+ children were found overweight or obese vs. 12.1% of DCD- children based on percentage body fat. These numbers were 25% vs. 15%, respectively, when BMI was used. In a study by Wahi (2011), 46,0% of children in the pDCD group had abdominal obesity vs. 15,9% in the control group. Tsiotra (2006) tested for clinical obesity in a Canadian and a Greek sample. In both samples the DCD+ group contained a significantly higher percentage of clinically obese children than the DCD- group. Schott (2007) and Fong (2011) also found a significantly higher percentage of children with pDCD to be overweight or obese than their TD peers. One study by Cairney (2010) actually assessed the risk for overweight and obesity among children with and without pDCD. They found children with pDCD to be at significantly higher risk for overweight and obesity. For obesity, the risk increased over time among children with pDCD, whereas it remained constant in the TD group.

Gender
Of the 8 studies that assessed the effect of gender on the relationship between DCD and body composition, only the study by Cairney (2005) reported a significant difference between boys and girls.

Age
All of the studies, containing children aged 9 years or older, that assessed the effect of age found it not to be significant. One study found significant between group differences in overweight and obesity among children aged 10 to 12 years, however these differences were not significant for children aged 4 to 9 years (Schott. et al., 2007).

Table 6. ***Summary of data extraction***

Author (year)	study design	Population	DCD assessment tool +percentile rate(s) used	DSM-IV criteria assessed	Outcome measure(s)	Outcomes / results	Relevant conclusions drawn in study	Relevant study limitations
Cairney (2005)	Cross-sectional	590 children, age 9-14y 44 children with pDCD (boys n=19, girls n=25)	BOTMP-SF $\leq 5^{th}$ percentile	A,C	BMI, Body fat (%)	Body fat: DCD+ group 23.3% overweight or obese / DCD- group 12.1% overweight or obese. (significant; p=0.037) BMI: DCD+ group 25% overweight or obese / DCD- group 15% overweight or obese. (not significant; p= 0.060) Gender differences: significant for boys, but not for girls. (BMI & body fat) No significant age differences	For boys DCD may be risk factor for overweight or obesity in childhood and adolescence, but not for girls.	Small sample size. No standard for food/water intake before measurement of body composition.
Cairney (2010)	Longtitudinal (prospective cohort) 2Y	2278 children, age 9-10y at baseline 111 children with pDCD (boys n=46, girls n=65)	BOTMP-SF $\leq 5^{th}$ percentile	A,C,D	BMI, waist circumference	Baseline: DCD+ children 15% higher BMI and 12% higher waist circumference (both significant). Risk for obesity increased over time for DCD+ children but remained relatively constant over time for DCD- children. No significant differences between boys and girls.	Children with pDCD have a higher risk of overweight or obesity.	Criterion C could not be fully addressed. Motor coordination testing was performed at different times for different students.
Cairney (2011)	Cross-sectional	126 children, mean age 12.4y (SD=0.5) 63 children with pDCD (boys n=37, girls n=26)	MABC-2 $\leq 5^{th}$ percentile. Between 6^{th} and 15^{th} percentile.	A,D	BMI, body fat (%)	Significant differences in % body fat among groups: 28% in 5^{th} percentile group, 23,6% in 15^{th} percentile group and 19,3% in TD group.	Children with pDCD have much higher body fat than their peers, this difference increases with severity of observed motor coordination problems.	Four children were included who had IQ less than 70 (Not including these children in the results however gave no differences).

						BMI was 24,0 in 5th percentile group, 21,3 in 15th percentile group and 20,2 in TD group (significant). No significant differences between boys and girls.	Children with DCD are at much greater risk for unhealthy weight than TD children	Test for criterion D was merely a brief tool, not a comprehensive assessment.
Wahi (2011)	Cross-sectional	126 children, aged 12.4 (0.52 SD) 63 children with pDCD (boys n=37, girls n=26)	MABC-2 ≤ 15th percentile.	A	Waist circumference	Abdominal obesity: 29 children (46,0%) in pDCD group, 10 children (15,9%) in control group. Difference was significant ($p<0.01$)	Children with pDCD had significantly greater abdominal obesity.	Gender not taken into account.
Faught (2005)	Cross-sectional	571, ages 9-14y 7,5%(± 3) with pDCD	BOTMP-SF ≤ 10th percentile.	A	Body fat (%)	Children with pDCD had significantly higher % body fat than control group ($p<0.001$). Interactions between gender and DCD on body fat were not significant.	Motor deficit leads to higher body fat.	None
Tsiotra (2006)	Cross-sectional	591 Canadian children, average age 11.46y / 329 Greek children, average age 11.3y Canadian children 8% DCD / Greek children 19% DCD	BOTMP-SF ≤ 12th percentile.	A	Body fat (%)	Canadian: 23% of DCD+ group is found clinically obese / 12% of DCD- group is found clinically obese. Greek: 48% DCD+ group is found clinically obese / 25% of DCD- group is found clinically obese. Differences were found significant ($p\leq0.05$).	None	Gender not taken into account.
Schott (2007)	Cross-sectional	261 children, ages 4-12y (three groups: 4-6y, 7-9y, 10-12y) 123 pDCD (52 moderate: boys n=24,	MABC ≤ 5th percentile (severe DCD). Between 6th and	A,C,D	BMI	A significant difference ($p=0.014$) in % overweight/obesity between DCD+ and DCD- was found in age group 10-12y(DCD severe: 50%, DCD	None	None

		girls n=28) (71 severe: boys n=48, girls n=23)	15th percentile (moderate DCD).			moderate: 23,1% vs TD medium: 5,6%, TD high: 0%). In age groups 4-6y and 7-9y, no significant difference was found. No significant differences between boys and girls.		
Cantell (2008)	Cross-sectional	110 children, divided in three age groups. Only age group 8-9y (n=29) met inclusion criteria Number of pDCD not clearly described	MABC ≤ 15th percentile.	A,B,D	BMI	Mean BMI in DCD- group, male=16,42 female=15,70 Mean BMI in DCD+ group, male=20,76 female=18,52 (difference significant). No significant differences between boys and girls.	None	Sample size unclear.
Tsiotra (2009)	Cross-sectional	177 children, aged 10-12y 12 pDCD (boys n=6, girls n=6)	BOTMP-SF ≤ 10th percentile.	A,C	BMI	DCD+ group had significantly higher BMI than control group ($p<0.05$). Mean BMI values were 23,51 in DCD+ boys vs. 20,56 in DCD- boys, and 22.84 in DCD+ girls vs. 19,82 in DCD- girls. No significant differences between boys and girls.	Children with DCD appear to have higher BMI values than their normal peers.	Small sample size.
Wu (2010)	Cross-sectional	41 children, aged 9-11y 20 pDCD (boys n=9, girls n=11)	MABC ≤ 5th percentile.	A,C,D	BMI, body fat (%)	Mean % body fat: 22,6% in DCD+ group vs. 22,5% in DCD- group. Mean BMI: 19,1 in DCD+ group vs. 17,4 in DCD- group. Differences were not found to be significant (p=0.963 &	None	Children scoring between the 6th and 15th percentile were not included in the laboratory tests. Gender differences were not taken into account.

						p=0.100 respectively).		Small sample size.
Fong (2011)	Cross-sectional	148 Children, mean age DCD group 8.07y (±1.5y) mean age control group 8.25y (±1.6y) 81 DCD (boys n=63, girls n=18)	BOTMP ≤ 15th percentile.	A,B,C,D (i.e. formal diagnosis)	BMI	DCD+ group had mean BMI of 18,85 and DCD- group had mean BMI of 17,65. 29,63% of children in DCD+ group were overweight or obese vs 7,46% of children in DCD- group. Differences were found significant (p<0.05). No significant differences between boys and girls.	A higher proportion of children with DCD tended to be overweight than children without the disorder.	None
Li (2011)	Longtitudinal (prospective cohort) 3y	50 children, aged 9y at baseline 25 pDCD (boys n=11, girls n=14)	MABC ≤ 5th percentile.	A,C	BMI, body fat (%)	Mean % body fat: TD group 1st year 20.1, 2nd year 19.9, 3rd year 19.8 DCD group 1st year 22.9, 2nd year 23.0, 3rd year 23.0 Mean BMI: TD group 1st year 16.8, 2nd year 16.9, 3rd year 16.9 DCD group 1st year 18.0, 2nd year 18.5, 3rd year 19.3 Differences were not significant (p>0.05).	None	Children between 6th and 15th percentile were not included in the study. Small sample size. Gender differences were not taken into account.
Chirico (2011)	Cross-sectional	126 children, aged 12-13y 63 pDCD	MABC-2 ≤ 15th percentile.	A,D	BMI, body fat (%)	Mean BMI in pDCD group was 23.4 and in control group 20.2 Mean % body fat in pDCD group was 28.3 and in control group 20.0 These differences were significant (p=0.001 for both BMI and % body fat).	None	Four children were included who had IQ less than 70 (excluding these children from the results however gave no differences). Gender differences were not taken into account.

						There were no differences between groups in fat free mass.		
Chirico (2012)	Longtitudinal (prospective cohort) 3y	86 children, aged 12y at baseline 33 pDCD	MABC-2 $\leq$ 15th percentile.	A,D	BMI, body fat (kg)	Mean BMI: DCD group 1st year 23.2, 2nd year 24.4, 3rd year 25.6 TD group 1st year 19.9, 2nd year 20.5, 3rd year 21.3 Mean kg body fat: DCD group 1st year 18.4, 2nd year 21.5, 3rd year 22.9 TD group 1st year 10.2, 2nd year 11.1, 3rd year 11.3 These differences were found significant ($p \leq 0.001$ for all, except for difference in BMI in first year which is $p \leq 0.01$). Fat free mass did not differ between groups.	None	None Gender differences were not taken into account.

Discussion

The main aim of this review was to assess whether children with DCD are at a greater risk of developing overweight or obesity and whether age and gender are predictor variables. At first sight the majority of the included studies appear to support the hypothesis that children with DCD are indeed at a higher risk of developing overweight and obesity. Several potentially limiting aspects of these studies however need to be taken into account.

Part of the measurements that were used to assess body composition, present issues. BMI is a frequently used measure in assessing overweight and obesity, however its correlation with fat mass in young children has been shown to be weak (Dietz, et al., 1998; Pietrobelli, et al., 1998). Furthermore, because BMI does not discriminate between different tissues, it can overestimate body fat (Rowland, 1996). Although waist circumference has been found valid for estimating abdominal fat in children (Taylor, et al., 2000), a consensus on cut off points for overweight and obesity is lacking. The percentile rate that is used to identify children as having DCD, also needs to be addressed. The 5^{th} percentile has been proposed by the 2006 Leeds consensus (Sugden, 2006) as the cut off point for diagnosing DCD, however it is also advised to monitor children scoring at or below the 15^{th} percentile. Different studies have used different cut off points for assigning children to the DCD group. This makes that the results of different studies may not be directly comparable, as (probable) DCD groups might differ in severity of motor impairment. Besides the issue of comparability, there is also the question whether results based on children scoring above that 5^{th} percentile are representative of the population (i.e. children with DCD).

Another important factor is the lack of a complete diagnosis of DCD. A formal diagnosis of DCD requires all four of the DSM-IV criteria to be met. Most studies did not asses all of these criteria, and as a result the term 'probable' DCD is often used to describe children that represent the population of children with the disorder.

Of all the included studies, only one actually met all four of the DSM-IV criteria and was able to make a formal diagnosis of DCD (Fong, et al., 2011). Consistent with most other studies, they did find children with DCD to have significantly higher BMI values and greater risk of overweight and obesity compared to TD children. Although these results are promising, the cut off point used for assigning children to the DCD group was the 15^{th} percentile. Strikingly, while mean BMI was 18.85 in the DCD group vs. 17.65 in the control group, the percentages of overweight and obese children were 29.63 vs. 7.46 respectively. An explanation for these different numbers was not given.

Among the other studies that used BMI as a measure, the majority also reported significant between group differences. In a 2 year prospective cohort study by Cairney (2010), BMI was used to calculate the risk for overweight and obesity. Children in the DCD group were found to be at higher risk for overweight and obesity than their TD peers. For obesity this risk actually increased over time in the DCD group, whereas it remained the same in the TD group. Most of the studies that used body fat as a measure also found significant between group differences. Tsiotra (2006) used body fat as a measure in a study that compared a Canadian and a Greek sample. Interestingly, percentages of body fat in both groups of the Greek sample were much higher compared to the Canadian sample. The given explanation for this difference was that Greek children are generally less active than children from other countries. The 2 studies that used WC as a measure both found the differences between groups to be significant.

In 3 of the included studies, between group differences were not significant. 2 Studies reported no significant differences in BMI as well as percentage body fat between children with pDCD and TD children (Wu, et al., 2010; Li, et al., 2011). Possibly, results were influenced by the small sample sizes in both these studies (DCD groups n=20 and n=25 respectively). Furthermore, both studies scored relatively low on the methodological quality assessment compared to the other studies. Cairney (2005) also used both BMI and body fat to measure body composition. Between group differences were found significant when body fat was used but not when using BMI. These contradictory findings could perhaps also be explained by the small sample size (n=44) in that study, however it could also

be the result of a difference in sensitivity between measures. Although differences were not found significant in these studies, all three did show a trend.
Results from only those studies that used the 5th percentile as a cut off point, were also compared as there exists a consensus on that cut off point for identifying children as having DCD. Surprisingly, all of the 3 studies with negative results(Wu, et al., 2010; Li, et al., 2011; Cairney, et al., 2005) were among the 6 studies using the more stringent cut off point. Again, the small sample sizes and poor methodological quality of these studies however may explain the aberrant results. Using much larger sample sizes (DCD groups ranging from n=63 to n=123), the other three studies all did find significant differences between groups. Cairney (2011) used both the 5th and the 15th percentile as cut off points to create 2 DCD groups, in order to test for a dose-response relationship. Their results showed that children in the DCD groups not only had much higher body fat than their peers, but that this difference increased with the severity of motor impairment.
The effect of gender on the relationship between DCD and body composition was assessed by 8 of the included studies. All but one found no significant difference for boys and girls. Cairney (2005) reported between group differences to be significant for boys only. It is possible that the relatively small sample size in this study accounted for this aberration.
Age effects were assessed by several studies containing children aged 9 years or older, all of which found no significance. In fact, only three studies contained children under 9 years of age and only one of these provided information on possible age effects. Schott (2007) included children aged 4 to 12 years old and divided them into three age groups. They found significant between group differences for children 10-12 years old but not for children aged 4 to 9 years. Possibly, the risk for overweight and obesity increases over time and does not become apparent before a certain age. This seems to be supported by the findings of Cairney (2010), who saw the risk for obesity increase over time among children in the DCD group. However, more longitudinal research on the potential effect of age on the relationship between DCD and body composition is needed to confirm this.
Certain aspects of this review need to be addressed as they form potential limitations. First of all, the methodological quality of the included studies was assessed through subjective analysis, as a gold standard is currently lacking. This makes that assumptions, based on this assessment, should be treated with prudence. Second, there is the question of causal ordering. Although the majority of research on the relationship between DCD and body composition assumes that poor motor coordination leads to overweight or obesity, the opposite has also been proposed (Wagner, et al., 2011). There is some evidence that overweight and obesity negatively affect gross and fine motor skills in children (D'Hondt, et al., 2008; Morano, et al., 2011). However, signs of DCD are usually presented much earlier than the actual overweight or obesity. Furthermore, as research has shown a dose-response in the relationship between DCD and body fat, it remains more likely that DCD is a risk factor for overweight and obesity.
In spite of any limitations, the evidence presented in this review seems to clearly supports the hypothesis that children with DCD are indeed at substantially greater risk of developing overweight and obesity than their typically developing peers. It is therefore strongly recommended that prevention and treatment of overweight and obesity be integrated in the existing therapies for DCD. As children scoring at or below the 15th percentile have also been shown to be at greater risk for overweight and obesity, merely monitoring these children might not be sufficient.
More Longitudinal research is needed for a full understanding of the effect of age on the relationship between DCD and overweight and obesity. In future research, it would seem advisable to make a full diagnosis of DCD as this strengthens any conclusions based on the results. The preferred measures for body composition in future research are WC and body fat as the sensitivity of BMI may not be sufficient. As some evidence exists on a dose-response effect in the relationship between DCD and body fat, it would also be advised to use different cut off points (i.e the 5th & 15th percentile) for identifying moderate and severe DCD groups.

Conclusion

Children with DCD are likely to be at greater risk of developing overweight and obesity than typically developing children, regardless of gender. This risk seems to increase with the severity of observed motor coordination problems. Also, this risk may increase over time and might not become apparent before a certain age.

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