Research in Developmental Disabilities 74 (2018) 72–102

Contents lists available at ScienceDirect

Research in Developmental Disabilities

journal homepage: www.elsevier.com/locate/redevdis

Evaluating the evidence for motor-based interventions in developmental coordination disorder: A systematic review and meta-analysis

Bouwien Smits-Engelsman[a,*], Sabine Vinçon[b], Rainer Blank[b,c], Virgínia H. Quadrado[a], Helene Polatajko[d], Peter H. Wilson[e]

[a] *Department of Health and Rehabilitation Sciences, University of Cape Town, Cape Town, South Africa*
[b] *Clinic for Child Neurology and Social Pediatrics, Child Centre Maulbronn, Maulbronn, Germany*
[c] *University of Heidelberg, Heidelberg, Germany*
[d] *Department of Occupational Science and Occupational Therapy, University of Toronto, Toronto, Ontario, Canada*
[e] *School of Psychology, Australian Catholic University, Melbourne, Australia*

ARTICLE INFO

Keywords:
Developmental coordination disorder
Motor impairment
Motor skill disorders
Motor skill programmes
Intervention
Physical therapy
Occupational therapy
Task oriented training
Physical activity
Systematic review

ABSTRACT

Background: As part of the process of creating an update of the clinical practice guidelines for developmental coordination disorder (DCD) (Blank, Smits-Engelsman, Polatajko, & Wilson, 2012), a systematic review of intervention studies, published since the last guidelines statement was conducted.
Aim: The aim of this study was to 1) systematically review the evidence published from January 2012 to February 2017 regarding the effectiveness of motor based interventions in individuals with DCD, 2) quantify treatment effects using a meta-analysis, 3) examine the available information on different aspects of delivery including use of group intervention, duration and frequency of therapy, and 4) identify gaps in the literature and make recommendations for future intervention research.
Method: An electronic search of 5 databases (PubMed, Embase, Pedro, Scopus and Cochrane) was conducted for studies that evaluated motor-based interventions to improve performance for individuals with DCD.
Results: Thirty studies covering 25 datasets were included, 19 of which provided outcomes on standardized measures of motor performance. The overall effect size (Cohen's *d*) across intervention studies was large (1.06), but the range was wide: for 11 interventions, the observed effect was large (> 0.80), in eight studies moderate (> 0.50), and in five it was small or negligible (< 0.50). Positive benefits were evident for activity-oriented approaches, body function-oriented combined with activities, active video games, and small group programs.
Conclusion: Results showed that activity-oriented and body function oriented interventions can have a positive effect on motor function and skills. However, given the varied methodological quality and the large confidence intervals of some studies, the results should be interpreted with caution.

What this paper adds

This comprehensive systematic review shows that recent data support the immediate benefits on performance of relatively short duration intervention (both activity-oriented and body function-oriented combined with activities), active video games, and small group programs.

Our review also shows the need for more rigorous RCTs with follow-up to demonstrate sustained change rather than just short-term gains in performance.

* Corresponding author.
E-mail address: bouwiensmits@hotmail.com (B. Smits-Engelsman).

https://doi.org/10.1016/j.ridd.2018.01.002
Received 25 May 2017; Received in revised form 7 January 2018; Accepted 13 January 2018

Important gaps in the literature have been identified. Controlled studies that compare different intervention approaches, group-based versus one to one intervention, subgroups of DCD on immediate and long term motor outcomes, on participation in physical activity outcomes, and on psychological factors are needed.

1. Introduction

Developmental Coordination Disorder (DCD) is one of the most common movement disorders of childhood and a condition that most children do not out-grow (Cantell, Kooistra, Cermak, & Larkin, 2002; Hill, Brown, & Sorgardt, 2011; Kirby, Williams, Thomas, & Hill, 2013; Losse et al., 1991; Geuze & Borger, 1993; Cantell, Smyth, & Ahonen, 1994). DCD is associated with a range of motor, cognitive, social and psychological issues that negatively affect everyday function (Hay, Hawes, & Faught, 2004; Venetsanou et al., 2011; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013; Wilson et al., 2017). These facts underscore the need for effective intervention to enhance motor skills and the ability to function in everyday life (Au et al., 2014). As part of the process of creating new clinical practice guideline for DCD (Blank, Smits-Engelsman, Polatajko, & Wilson, 2012), a prior systematic review of DCD intervention studies published between 1995 and 2011 was conducted. In that review (Smits-Engelsman et al., 2013), we concluded that task oriented approaches were most beneficial on functional outcomes. We noted, however, that few randomized controlled trials (RCTs) were available. Other issues at that time were a need for stricter application of DSM (Diagnostic and Statistical Manual of Mental Disorders) criteria and consistency in the terms used to describe participants (Geuze, Schoemaker, & Smits-Engelsman, 2015).

Five years later, we present here an update as part of the 5-yearly revision required by Guidelines International Network of the clinical practice guideline for DCD. The main aim of this paper is to present the results of a systematic evaluation of new evidence on the effectiveness of interventions.

1.1. Description of the condition

By definition, children with DCD show characteristic difficulties in performing fine- and/or gross-motor skills to the level of their peers, and exhibit performance difficulties in the tasks of everyday living (American Psychiatric Association, 2013). In the language of the International classification of functioning, disability and health (ICF; WHO, 2001) DCD is manifest in the area of body function and structure (e.g., motor control processes, Blank et al., 2012), activity, and participation (Cairney & Veldhuizen, 2013). A prevalence rate of around 5–6% for DCD is not trivial in school-aged children, with a somewhat higher incidence in boys than girls (Cairney, Hay, Faught, & Hawes, 2005; Lingam et al., 2010; Missiuna, Gaines, Soucie, & McLean, 2006; Venetsanou et al., 2011). Critically, nearly half of those diagnosed in early childhood continue to have difficulties into adolescence and early adulthood (Kirby et al., 2013). In addition, children with DCD frequently experience a range of comorbid problems including attentional issues (viz Attention Deficit Hyperactivity Disorder – ADHD), behavioral issues, language, and psychosocial problems including anxiety, depression and low self-esteem. In general, the higher the severity of DCD and the more comorbid issues, the poorer the outcome (Peters, Barnett, & Henderson, 2001). Poor motor coordination also results in reduced physical activity participation and lower fitness outcomes in populations with DCD (Rivilis et al., 2011; Schott, Alof, Hultsch, & Meermann, 2007). Consequently, the risk of developing obesity and cardiovascular diseases is increased (Faught, Hay, Cairney, & Flouris, 2005; Cantell & Crawford 2008). This cluster of developmental problems and the persistent nature of DCD show the importance of intervention that enhances activity and supports participation (Smits-Engelsman et al., 2013; Smits-Engelsman, Magalhaes, Oliveira, & Wilson, 2015; Wilson et al., 2013).

1.2. Description of the interventions

There have been numerous activity based approaches to intervention for DCD (Miyahara, Hillier, Pridham, & Nakagawa, 2017; Smits-Engelsman et al., 2013; Wilson et al., 2013), traditionally grouped into two broad areas: those that use activity to target the underlying performance problems, often referred to as process oriented approaches, and, those that use activity to address the performance itself, often referred to as task oriented approaches.

In the review published in 2013, it was observed that task oriented approaches were more efficient than process oriented, yielding better functional performance outcomes in less time for children with DCD (Smits-Engelsman et al., 2013). Task oriented interventions are activity oriented but also clearly facilitate participation. Characteristics of task oriented intervention are:

1. Client centred (meaningful for the client)
2. Goal oriented: Aiming at activities and participation as described in the ICF-Child and Youth (WHO, 2007).
3. Task and context specific
4. Involve active role of the client
5. Aimed at functionality not at normality
6. Aimed at active involvement of parent(s)/caretakers to enable transfer of learning to the every day context.

In the earlier stages of DCD research, intervention approaches were almost exclusively process oriented or in ICF terms, focused on reducing impairment and improving body function and structure (Smits-Engelsman et al., 2013). These approaches were primarily medical or rehabilitative, and attempted either to prevent or ameliorate limitations in body function and structure by correcting or modifying them or by increasing capacity levels. Studies examining these approaches tended to report on changes at the level of body function and structure only. However, more recently, studies of body function oriented interventions have started to report on changes at the level of activity, and occasionally on participation. Similarly task oriented approaches, which tended to report only on changes at the level of activity and participation, have begun to broaden their scope by including outcomes related to body function and structure (Jelsma et al., 2014; Farhat et al., 2015).

A recent Cochrane review by Miyahara et al. (2017) was notable for targeting all available RCTs that evaluated task-oriented interventions specifically, regardless of publication date. Adhering to very strict inclusion criteria and fairly rigorous methodology, only 15 eligible studies were included (eight RCTs and seven quasi-RCTs), some dating back to 2000; of the total sample, only six were published after 2011. The main meta-analysis (involving six studies) showed a moderately positive effect on movement difficulties. The remaining nine studies were not combined for meta-analysis due to incomplete data or marked differences in the intervention per se. The main issue with Miyahara's review is that a large body of the evaluation literature (both RCT and Controlled Clinical Trials; CCTs) is not captured, especially the many studies published since 2011. If the concern is methodological quality, then rating all studies on their risk of bias can accommodate this. In any case, well-designed CCTs with high levels of evidence are important when evaluating new approaches to treatment. Large RCTs are not always possible or feasible, depending on the stage of research. Moreover, with a larger sample of studies, corroborating results from the same or very similar interventions can provide evidence of *consistency*, reducing the chance of spurious findings. In short, an updated review of DCD intervention is needed to provide a comprehensive critique of the current body of work that provides direction for researchers and clinicians alike.

To represent shifts in treatment approaches over recent years, we describe interventions reviewed here using the ICF terminology (WHO, 2007). Specifically, we describe interventions based on the level of the ICF that is the primary target of the intervention. This is a significant strength in methodology, allowing researchers and clinicians to interpret results within a broad and accessible conceptual framework. Interventions are identified as follows: (i) **body function and structure (BF) oriented,** where the activity engaged in is designed to improve targeted body functions considered to underlie the reported functional motor problem; (ii) **activity oriented** where the activity engaged in is designed to improve performance in that activity; and (iii) **participation oriented**, where the activity engaged in is designed to improve participation in that activity in an everyday life situation. In interventions identified as Activity- or Participation-oriented, the primary interest is to improve performance of particular activities or participation and the content of the intervention involves direct training of the skill concerned. Let us use the example. If stringing beads is used as an activity during intervention with the primary goal to improve eye hand coordination in a child with handwriting difficulties, it would be called BF oriented. In contrast, if in another child the goal of stringing beads were to improve the skill itself, it would be called an activity oriented intervention. If, to take it one step further, the goal were for the child to become better at stringing beads so he can make decorations with his friends it would be called activity and participation oriented.

1.3. Objectives

The core objective was to examine up to date evidence regarding motor-based intervention for individuals with DCD. More specifically, the review aimed to (1) describe new evidence (between January 2012-February 2017) regarding the effectiveness of interventions focusing on motor skills or on tasks relevant for everyday life or for improving general fitness and motor proficiency for DCD, (2) evaluate the level of evidence for each of these intervention approaches, (3) examine the available information on different aspects of delivery including use of group intervention, duration and frequency of therapy, and suitability for key groups (e.g., children of different ages, socioeconomic status, and with co-occurring conditions); (4) identify gaps in the literature and make recommendations for future intervention research.

2. Review methods

2.1. Search strategy for identification of studies

A systematic literature search of DCD-related studies was undertaken to identify eligible intervention studies for review. We identified studies from January 2012 up to February 2017 using electronic databases and the reference lists of retrieved studies. If needed, we contacted authors for additional information. A primary search of the biomedical literature was performed using PubMed and Cochrane databases with appropriate headings and keywords related to intervention for individuals with DCD. We adapted the search strategy developed for PubMed for use in the other electronic databases (Embase, Pedro, and Scopus). The combinations of search terms are shown in Table S1.

2.1.1. Inclusion criteria

Initially, any study reporting new data on the motor outcomes of intervention for children or adults with DCD (or those labeled probable-DCD) was selected for review. This included: randomized clinical trials, controlled clinical trials, case-control studies, cohort studies, longitudinal studies, and single-case experimental design studies. Studies were first read as abstracts only. From this initial pool, we selected any intervention study that aimed to improve motor functions, activities and/or participation outcomes. We included studies regardless of the type of intervention or delivery mode (one to one or group). All included studies were available as full-text articles. Review papers were handled separately and used for comparison purpose in the discussion.

2.1.2. Exclusion criteria

Studies published in languages other than English were excluded. We also excluded studies that reported *only* cognitive or physiological outcomes (e.g., motor control processes and brain-related activity such as event-related potentials—ERPs).

2.1.3. Types of outcome measure

The ICF was used as a framework for classifying outcomes addressing activity or skill improvement, which has been the primary

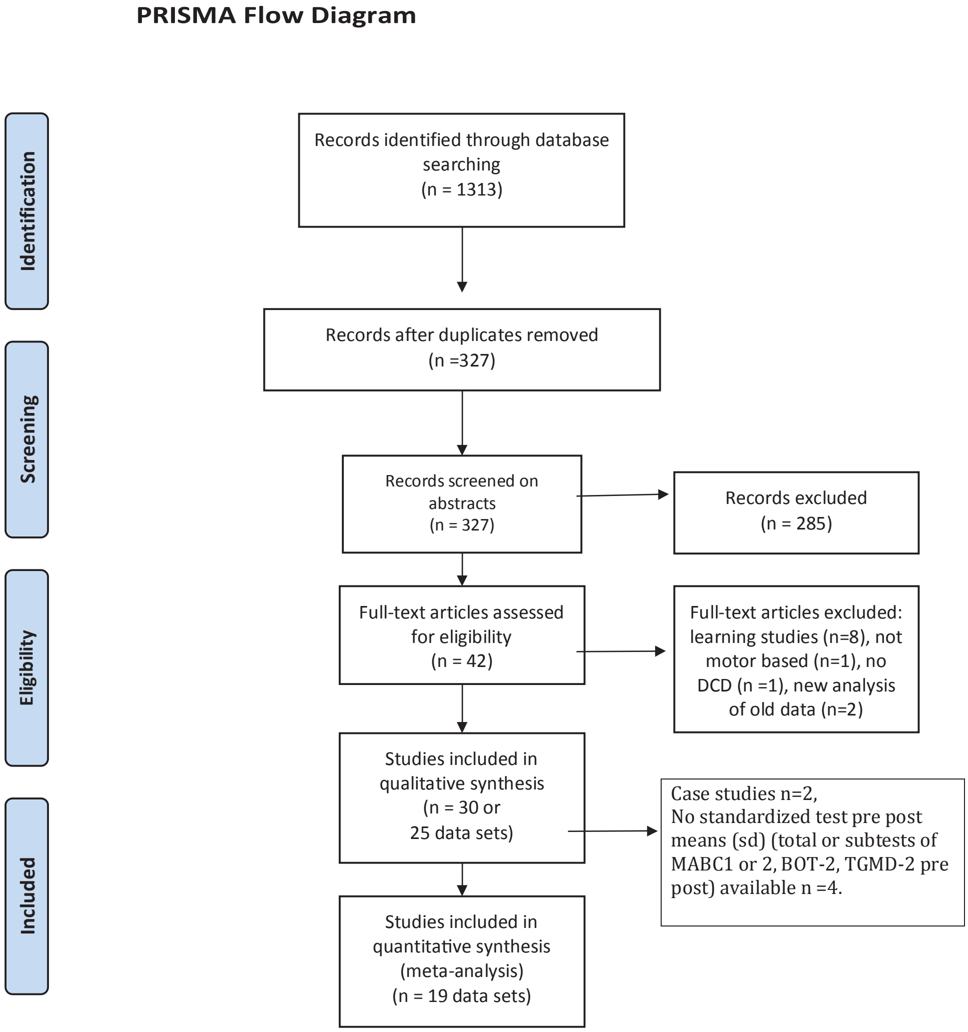

Fig. 1. Flowchart of the steps to select the papers for this review according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement.
From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. https://doi.org/10.1371/journal.pmed1000097. For more information, visit www.prisma-statement.org.

focus of intervention research for many years. To enhance the quality of the systematic review, we focused on validated and reliable measures to improve the comparability of the effects between studies. The most common measures found to be used were the Movement Assessment Battery for Children Test first or second edition (MABC-1 or −2), the Bruininks-Oseretsky Test of Motor Proficiency first or second edition (BOT-1 or −2), or agility and functional fitness tasks (i.e., everyday tasks like running and jumping, stair climbing or cycling); we classified these as activity level measures. We also found outcome measures that could be

Table 1
Level of Evidence form given to the reviewers in the present study.

	LEVELS OF EVIDENCE
1 + +	RCTs with a **very low** risk of bias.
1 +	RCTs with a **low risk** of bias.
1-	RCTs with a **high risk** of bias.
2 + +	High quality case control, clinical trials or cohort studies with a very low risk of confounding or bias and **a high probability** that the relationship is causal.
2 +	Well-conducted case control, clinical trials or cohort studies with a low risk of confounding or bias and a **moderate probability** that the relationship is causal.
2-	Case control, clinical trials or cohort studies with a high risk of confounding or bias and a significant risk that the relationship is **not causal.**
3	Non-analytic studies, e.g. case reports, case series.

Table 2
The following characteristics are summaries of the included studies: levels of evidence, kind of study, population description, number of participants, age, ratio boys/girls, DSM criteria, cut off values on the test, and relevant baseline test results, type of intervention, frequency, intensity and duration, outcome measures, description of results, and short description of the conclusion. Studies having an a/b/c in the first column after their number refer to publications that analyze the same data set.

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
1	3 NCT	Ashkenazi et al., 2013	DSM-5: yes, criteria A,C and D, 16th $n = 9$ Boys: 7 Girls: 2 Age: 4–6 y Mean age: 5.6 ± 0.6 Suspected DCD	***Activity-oriented: Virtual Reality Training*** ● Plus Goal-directed tasks ● Individual intervention	***No control group***	● 1 h/session ● 10 sessions ● 12 weeks		● MABC-2 ● 6-MWT ● 10-MWT ● DCD-Q ● parents' subjective report (satisfaction and child's intervention response)	AVG seemed to be effective in improving motor capabilities (MABC-2, DCD-Q) in children with DCD.
2	1+ RCT	Au et al., 2014	DSM-5: yes, all criteria, 16th $n = 22$ Boys: 15 Girls: 7 Age: 6–12 y DCD (1): ($n = 11$, 8 boys, 3 girls) Mean age (months): 91.5 ± 13.0 DCD (2): ($n = 11$, 7 boys, 4 girls) Mean age (months): 95.2 ± 12.1	***Body function oriented*** ● Core stability (physio ball exercises) Individual	***Activity-oriented: Sport/play related skill training*** ● Task-oriented training Individual	● 1 h/session ● 1x/week ● 8 weeks plus daily homework	● SOT	● BOT-2 (Short form) ● Parental satisfaction questionnaire	Core stability programs and task-oriented motor programs both enhanced motor proficiency in children with DCD. Task-oriented training better results on balance.

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
3	3 Case	Baldi et al., 2015	DSM: no, NA n = 3 Boys: 3 Girls: no Age: 9–10 DCD with poor handwriting	***Activity-oriented:*** Handwriting Training ● Individual intervention	***No control group***	● 45′/session ● 2 x/week ● 13 weeks ● additional 15–20′ (home activities, 5-6 days/week)	● VMI	● Evaluation of dysgraphic features in handwriting performance Battery for assessment of writing skills (BV-COS)	The HTP can reduce the number of visual-spatial errors, inadequate motor learning errors, and motor efficiency errors, and improve the quality of handwriting in children with developmental disabilities and poor handwriting quality. However, in one child with DCD handwriting difficulties persisted after HTP.
4	2- CCT	Cacola et al., 2016	DSM-5: yes, all criteria 9th n = 24 Boys: 19 Girls: 5 Age: 7–12 y DCD (1): (n = 11, 10 boys, 1 girl) Mean age: 9.09 ± 1.51 DCD (2): (n = 13, 9 boys, 4 girls) Mean age: 8.46 ± 1.5	***Activity-oriented: Sport/play related skill training (1)*** ● Task-oriented training ● Group intervention	***Activity-oriented: Sport/play related skill training (2)*** ● Goal-oriented training ● Group intervention	● 1 h/session ● 1x/week ● 10 weeks	● SCAS	● MABC-2 ● CSAPPA ● CAPE ● PAC ● SDQ ● ChAS ● DCD-Q	Both group-based task-oriented training and goal-oriented training were effective in improving balance and overall motor skills in children with DCD.

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
5	1 RCT-CO	Coetzee & Pienaar, 2013	DSM-5: yes, all criteria, 16th	***Body function oriented***	***No intervention***	• 40′/session • 1x/week • 18 weeks	• SISST • QNST-2	• MABC	Visual therapy programs are effective in improving the ocular motor control skills in children with DCD who experience poor ocular motor control. For most children, improvements are sustained two years after intervention.
			$n = 32$	• (visuo) Motor Skill-oriented training • A combination of perceptual, motor and visual exercises • Individual intervention	• no intervention 18 weeks then cross-over and group 2 gets intervention				
			Boys: 20 Girls: 12 Age: 7–8 y DCD (1): Visual therapy ($n = 16$, 10 boys, 6 girls) Mean age (months): 95.87 ± 3.34 DCD (2): Control ($n = 16$, 10 boys, 6 girls) Mean age (months): 95.5 ± 3.83 Group cross-over						
6a	2+ CCT	Farhat et al., 2015	DSM-5: yes, all criteria, 16th	***Activity-oriented: Sport/play related skill training***	***Control intervention***	• 1 h/session • 3x/week • 8 weeks	• Physical Fitness Battery Test (Triple Hop Distance, 5 Jump-test),	• MABC • HPT • Modified Agility Test,	Group-based motor skills training is effective in improving gross- and fine-motor skills in children with DCD, leading to improved motor co-ordination and performance, and handwriting quality and speed. Improvements in physical ability (power, explosive strength, agility) with training were also observed.
			$n = 41$	• Task-oriented training	Regular classroom activities and PE classes				

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
			All boys Age: 6–10 y DCD: experimental (n = 14) Mean age: 8.8 ± 1.0 DCD: control (n = 13) Mean age: 8.5 ± 0.6 TD: control (n = 14) Mean age: 8.6 ± 0.9	Group based	● DCD *group* ● TD group				
6b	2+ CCT	Farhat et al., 2016	See Farhat 2015	See Farhat 2015	See Farhat 2015	See Farhat 2015	● CPET	● MABC ● PCERT ● 6-MWT	Motor skill training program for children with DCD is effective in improving motor performance, cardiorespiratory fitness, aerobic endurance, and exercise tolerance, and delays reaching the anaerobic threshold.
7	2++ CCT	Ferguson et al., 2013	DSM-5: yes, all criteria, 16th	***Activity-oriented: Task-oriented training/NTT (1)***	***Activity-oriented: Virtual Reality Training (2)***	● 45-60′/session ● 2x/week ● 9 weeks ● 30′/session ● 3x/week ● 6 weeks	● HHD ● MPST ● 20 m shuttle run test	● MABC-2 ● FSM	Compared to Wii training, group-based NTT intervention produced greater improvements in motor proficiency, cardiorespiratory fitness, and functional strength in children with DCD.
			n = 46	● NTT ● NTT: group intervention	● Active Video Games ● Wii: Supervised Play				
			Boys: 24 Girls: 22 Age: 6–10 y DCD (1): NTT (n = 27, boys:15, girls: 12) Mean age: 8.22 ± 1.34 DCD (2): Wii training (n = 19, boys: 9, girls: 10) Mean age: 7.63 ± 1.07						

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
8	2+ CCT	Ferguson et al., 2015	DSM-5: yes, all criteria, 16th	***Activity-oriented: Sport/ play related skill training***	***No intervention***	● 9 weeks ● Weekly guidance for teachers and students using the 6 key features for HPP	● MPST ● Shuttle Run Test	● MABC-2 ● FSM	HPP can be implemented generically, and is beneficial to all children but children with and without DCD benefit differently. Although a health promotion approach may address some of the motor problems experienced by children with DCD; it cannot completely replace the need for professional intervention. However, the approach may be useful while children await further care or in addition to therapy services.
			n = 41	● Health Promotion (HPP) ● System intervention	no intervention TD group				
			Age:6–10 y Boys: 18 Girls: 23 DCD: (*n* = 22, 9 boys, 13 girls) Mean age: 7,7 ± 1.0 TD: (*n* = 19, 9 boys, 10 girls) Mean age: 8 ± 1,5						
9a	1- RCT	Fong et al., 2012	DSM-5: yes, all criteria, BOT < 42.	***Activity-oriented: Sport/ play related skill training (single skill: Taekwando)***	***No intervention***	● 1 h/session ● 1x/week ● 12 weeks	● SOT ● UST		Taekwondo training can remedy unilateral standing balance and vestibular function impairments in children with DCD.
			n = 62	● Sport specific ● Taekwondo training: group intervention ● Training at home: individual intervention	● no intervention DCD group ● no intervention TD group				
			Boys: 49 Girls: 13						

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
			Age: 6–9 y DCD: Taekwondo (n = 21, boys: 17, girls: 4) Mean age: 7.7 ± 1.3 DCD: control (n = 23, boys: 18, girls: 5) Mean age: 7.4 ± 1.2 TD: control (n = 18, boys: 14, girls: 4) Mean age: 7.2 ± 1.0						
9b	1- RCT	Fong et al., 2013	See Fong et al., 2012, 16th	See Fong et al., 2012	See Fong et al., 2012		● UST ● MCT ● Isokinetic quadriceps and hamstring muscle strength		Children with DCD who undergo Taekwondo training experience improvements in isokinetic knee muscle strength and static single-leg standing balance control, but do not benefit from improved reactive balance control.
10a	1++ RCT	Fong, Guo, Cheng et al., 2016	DSM-5: yes, all criteria, NA	***Activity-oriented: Sport/ play related skill training (1)***	***No intervention***	● 35′/session ● 2x/week ● 3 months ● assessment 3 months later ● total 6 months	● Primary outcomes: SOT ● Secondary outcomes: UST	● Secondary outcomes: MABC	Balance training was found to marginally improve the somatosensory function and somewhat improve the balance performance of children with DCD.
			n = 88	● Functional movement training (FMT) with biofeedback ● Individual intervention	● no intervention DCD group				
			Boys: 61 Girls: 27 Age: 6–10 y DCDFMT (1): 47 (boys 33, girls: 14) Mean age: 7,9 ± 1,4 DCDcon: 41 (boys 28, girls: 13) Mean age: 7,5 ± 1,6						

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics: Experimental	Intervention, Classification/Category, Specifics: Comparator	Treatment duration, Homework	Outcome assessment: Body Function	Outcome assessment: Activity & Participation	Authors' conclusions
10b	1 + + RCT	Fong, Guo, Cheng et al., 2016 plus extra group	DSM-5: yes, all criteria NA	***Activity-oriented: Sport/ play related skill training (1)***	***Activity-oriented: Sport/play related skill training (2)***	● 35′/session ● 2x/week ● 3 months ● assessment 3 months later ● total 6 months	● Primary outcomes: SOT ● Secondary outcomes: peak force		FMPT was more effective than FMT program in the enhancement of balance strategies (less reliance on hip strategies). Both FMPT and FMT are effective in improving overall balance. FMT produced force faster in the knee flexors. Improvement was maintained after 6 month in the FMT group. No data on motor test reported.
			See Fong 2016a	● Functional movement ● power training (FMPT) ● Individual intervention	● Functional movement training (FMT) with biofeedback ● Individual intervention				
			Plus extra Group DCD-FMPT: 42 (boys: 28, girls: 14) Mean age: 7,8 ± 1,3						
11	2- CCT	Giagazoglou et al., 2015	DSM: no, NA	***Activity-oriented: Sport/ play related skill training***	***No intervention***	Balance: ● 45′/session ● 3x/week ● 12 weeks	● TBCT ● 1 and 2 leg stance		Balance training circuit program, with a trampoline station, was effective in improving motor ability, body co-ordination, and balance performance in children with probable DCD. No data on motor test reported.
			n = 20	● Balance training circuit (including a trampoline station program) ● Group intervention ● Trampoline Koperkoordinations test fur Kinder < 85 for selection	TD control group	Control: ● regular schedule PE ● 40-45′/session ● 3x/week			
			Boys: not mentioned Girls: not mentioned Age: 8–9 y p-DCD: Balance training(*n* = 10)						

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics: Experimental	Comparator	Treatment duration, Homework	Outcome assessment: Body Function	Activity & Participation	Authors' conclusions
			Mean age = 8.80 ± 1.7 TD: control (n = 10) Mean age: 8.43 ± 1.85						
12	1+ RCT	Hammond et al., 2014	DSM-5: all criteria, NA	***Activity-oriented: Virtual Reality Training (1)***	***Activity-oriented: Sport/play related skill training (2)***	● 10′/session ● 3x/week ● 4 weeks		● BOT-2 ● CSQ ● SDQ (n = 7)	Wii Fit balance games may lead to gains in BOT-2, CSQ, and SDQ for many, but not all children.
			n = 18	● Supervised ACG Play	Usual 'Jump Ahead program' (1 h/week) ● cross-over design				
			Boys: 14 Girls: 4 Age: 7–10 y DCD: Wii (1) training (n = 8, boys: 8, girls: 2) Mean age: 8.53 ± 1.15 DCD: Comparison (2) (n = 10, boys: 6, girls: 2) Mean age: 9.53 ± 1.42						
13	2++ CCT-CO	Jelsma et al., 2014,	DSM-5: yes, all criteria, 16th	***Activity-oriented: Virtual Reality Training***	***No intervention***	● 30′/session ● 3x/week ● 6 weeks		● MABC-2 ● BOT2 (bilateral coordination, balance and running speed & agility tested)	For children at risk for DCD and balance problems, Wii Fit intervention is effective in improving motor performance and balance skills.
			n = 48 Mean age: 6–12 y DCD Balance problems (BP) (n = 28) in sub-groups: ● BP1 (n = 14) Mean age months: 104.8 ± 17 Sex ratio f/m: 0.36 ● BP2 (n = 14,) Mean age months: 92 ± 14.1 Sex ratio f/m: 0.36 ● TD (n = 20) Mean age (months): 102.5 ± 12.2 Sex ratio f/m: 0.45	● Supervised Play	DCD control group (cross over) TD control group				

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
14	1+ RCT	Kordi et al., 2016	DSM-a: yes, NA	***Body Function oriented (1)***	***Control:***	● 60′/session ● 2x/week ● 12 weeks	HHD	BOT-2 (balance subtest)	Strength training significantly increased muscle strength in DCD children and improved their static balance performance. There was not an improvement in dynamic balance.
			n = 30	Strength training using flexible Theraband elastic exercise	DCD control				
			Age: 7–9 y		Routine physical education class				
			DCD 1 Age: 8.01 ± 0.54 5 girls, 10 boys DCD control (2): Age: 7.70 ± 0.63 3 girls, 12 boys						
15	3 Case	Menz et al., 2013	DSM: no, NA	***Body function oriented***	***No control group***	● 24 sessions according to the schedule of the patient		● BOT	Improvement on strengthening, but without clinical relevance
			n = 1 DCD	● Strength Training ● Individual intervention					
			1 girl Age: 6 y 11 m						
16	2+ CCT	Noordstar et al., 2017	DSM-5: yes, criteria A, B, C, D; 16th	***Activity-oriented:***	***Activity-oriented:***	● 30′/session ● 1 x/week ● 12 weeks		MABC2;	Both interventions improved movement skills (pre-post), with no differential effect of group; motor gains remained at 3-month follow-up;
			N = 31 (21 boys); aged 7–10 years;	task-oriented motor training + perceived competence training	task-oriented motor training			DCD-Q	Self perceptions of motor ability also improved in both groups after training, and tended to remain at follow-up.
			DCD1: *n* = 20 (13 boys) **DCD 2** *n* = 11 (8 boys)	(using verbal feedback strategies) Individual	Individual			SPPC	
17	2- CCT	Smits-Engelsman et al., 2017	DSM-5: yes, all criteria 5th	***Activity-oriented: Virtual Reality Training***	*Same intervention* TD control group	● 20′/session ● 2x/week ● 5 weeks	● Yoga stance on Balance Board	● MABC: Balance tasks	Improvement in motor abilities and balance

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
			n = 34 Boys: 18 Girls: 16 Age: 6–10 y DCD = 17 (boys: 9, girls: 8) TD = 17 (boys: 9, girls: 8)	● Supervised Play					
18	2+ CCT	Smits-Engelsman et al., 2017	DSM-5: yes, criteria A, B, C, D, 16th	***Activity-oriented: Virtual Reality Training***	***Same intervention***	● 20′/session ● 2x/week ● 5 weeks	● FSM ● 10 m sprint test ● 10 m slalom test	● MABC-2 ● BOT-2 (balance and running speed & agility subtest)	After intervention, both groups improved in functional strength and anaerobic fitness. Children with DCD seemed to benefit more in balance skills on the BOT-2, TD children more in running speed and agility.
			n = 18 Age: 6–10 y DCD group: Mean age: 8.2 ± 1.13 9 boys, 8 girls TD group: Mean age: 8.0 ± 1.22 9 girls, 9 boys	● Supervised Play	TD control group				
19a	1- RCT	Straker et al., 2015	DSM-5: yes, criteria A and D, 16th	***Activity-oriented: Virtual Reality Training***	***No intervention***	AVG: asked to play games for:	● 3-D motion analysis (finger-nose and balance tasks),	● MABC-2 ● DCDQ, rating of motor co-ordination (child and parent)	AVG interventions for children at risk for DCD did not enhance motor co-ordination skills; although perceived motor skills were greater following training in the
			n = 21		● no AVG (2) intervention; cross-over design after 16 weeks	● min 20′ ● min 4-5 days/week ● 16 weeks)			
19b	1- RCT	Howie et al. 2016	Boys: 10 Girls: 11 Age: 9–12 y	● Home intervention (1)					

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
19c	3 NCT	Larke et al., 2015	Mean age: 11.0 ± 1.0 Mean age boys: 10.8 ± 1.1 Mean age girls: 11.3 ± 0.8 DCD: AVG (1) (n = 10) DCD: NAG (2) (n = 11)				Accelerometer	Activity self reports	AVG intervention group compared to NAG. Among children at risk for DCD, participating in this AVG intervention did not improve objectively measured physical activity and sedentary time.
20	1+ RCT	Thornton et al., 2016	DSM-5: yes, all criteria, NA n = 20 All boys Age: 8–10 y Mean age: 9y 1m ± 9 m DCD: CO-OP (n = 10) DCD: control (n = 10)	***Activity-oriented: Task-oriented training (CO-OP)*** ● CO-OP ● Group Intervention	***No intervention*** DCD control group	● 1 h/session ● 1x/week ● 10 weeks ● additional 15′/day (home activity)	● 3-D motion analysis (motor overflow assessment) ● Flex-sensor glove	● MABC-2 ● HST ● COPM ● GAS	CO-OP group intervention for children with DCD can lead to improvements in motor overflow level, activity performance, and participation.
21	1- RCT	Tsai et al., 2012	DSM-5: yes, 16th, criteria for ADHD n = 52 Boys: 42 Girls: 12 Age: 9–10 y DCD (1): soccer training (n = 16, boys 9, girls 7) DCD (2): control (n = 14, boys 9, girls 5) TD: control (n = 22, boys 12, girls 10)	***Activity-oriented: Sport/play related skill training (Soccer)(1)*** Soccer training: Group intervention	***No intervention*** no intervention DCD control group TD control group	● 50′/session ● 5x/week ● 10 weeks	● ERP indices of the attention network	● MABC	Soccer training improve motor skills, inhibitory control, and ERP indices of the attention network

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
22	2+ CCT	Tsai et al., 2014	DSM-5: yes, all criteria, 5th	***Body function oriented***	***No intervention***	● 50′/session ● 3x/week ● 16 weeks	● PACER	● MABC	Endurance exercise training improved motor abilities, but not improve Reaction Time and Visual Spatial Working Memory
			n = 60	● Cardiorespiratory training ● Endurance training: group intervention	DCD control group TD control group				
			Boys: 37 Girls: 23 DCD:training (1) (n = 20, boys 13, girls 7) Mean age months: 137.80 ± 3.41 DCD:control (2) (n = 20, boys 12, girls 8) Mean age months: 138.35 ± 3.31 TD:control (3) (n = 20, boys 12, girls 8) Mean age months: 138.45 ± 5.41						
23	1++ RCT	Wilson et al., 2016	DSM-5: yes, criteria A, B, C, D, 10TH	***Activity-oriented: Motor imagery training (MIT)(1)***	***Activity-oriented: Sport/play related skill training (2)***	● 1 h/session ● 1 x week ● 5 weeks		● MABC-2	MIT was equally effective as PMT in promoting motor skill acquisition, with moderate-to-large effect sizes.
			n = 36 Age: 7–12 y DCD MIT n = 11 DCD PMT n = 13 DCD Control n = 11		Perceptual-motor therapy (PMT) ***and no intervention (3)*** no intervention (waiting list)				
24	2++ CCT	Yu et al., 2016	DSM-5: yes, all criteria,16th	***Activity-oriented: Sport/play related skill training***	***No intervention***	● 35′/session ● 2x/week ● 9 sessions ● 6 weeks		● TGMD-2 ● PSDQ ● CSHQ-C	It is suggested that short-term FMS training is effective in improving FMS and SPC and reducing sleep disturbances for children with DCD.

(*continued on next page*)

Table 2 (*continued*)

#	Levels of evidence	Reference	Sample characteristics: Ratio boys/girls, Mean age and range, DSM yes or no, which criteria, cut-off	Intervention, Classification/Category, Specifics		Treatment duration, Homework	Outcome assessment		Authors' conclusions
				Experimental	Comparator		Body Function	Activity & Participation	
			n = 84 Boys: 47 Girls: 37 Age: 7–10 y DCD: training (n = 22, boys 13, girls 9) Mean age: 8.2 ± 0.75 DCD: control (n = 16, boys 12, girls 4) Mean age: 8.9 ± 0.93 TD: training (n = 17, boys 8, girls 9) Mean age: 8.5 ± 0.62 TD: control (n = 29, boys 14, girls 15) Mean age: 8.9 ± 0.88	● Multi-skill Functional Movement Skill (FMS) training ● Group intervention	DCD control group TD control group				
25	3 NCT	Zwicker et al., 2015	DSM-5: yes, all criteria, NA *n* = 11 DCD Age: 7–12 y Mean age: 9.7 ± 1.8	***Activity-oriented: Task-oriented training (CO-OP)*** ● CO-OP ● Group intervention	***No control group***	COOP − 90′/session ● 4 sessions ● 2 weeks as part of summer camp: 5 days a week, 6 h a day for 2 weeks		● COPM ● PEGS ● CSAPPA ● CAPE	Group-based summer camp, using CO-OP intervention, was effective in improving the performance and performance satisfaction of child-chosen functional motor goals in children with DCD. No data on motor test reported.

Abbreviations: 6-MWT: 6-min walk test; 10-MWT: 10-min walk test; ADHD: Attention deficit hyperactivity disorder; AVG: active video games; BOT(-2): Bruininks-Oseretsky Test of Motor Proficiency(-2); BV-COS: Battery for assessment of writing skills; CAPE: Children's Assessment of Participation and Enjoyment; CCT: controlled clinical trial; ChAS: Children Activity Scale; CO-OP: Cognitive Orientation to (Daily) Occupational Performance; COPM: Canadian Occupational Performance Measure; CPET: Cardiopulmonary exercise test; CSAPPA: Children's Self-Perceptions of Adequacy in and Predilection for Physical Activity Scale; CSHQ: Children's Sleep Habits Questionnaire-Chinese version; CSQ: Coordination Skills Questionnaire; DCD: Developmental Coordination Disorder; DCD-Q: DCD-questionnaire; DSM-5: Diagnostic and Statistical Manual of Mental Disorders 5th edition; ERP: Event-related potential; FSM: Functional Strength Measure; GAS: Goal Attainment Scale; GSE: Global Self-Esteem; HHD: Hand-held dynamometer; HHP: Health Promotion Program; HPT: Handwriting Performance Test; HST: Handwriting Speed Test; HTP: Handwriting Task Program; MABC(-2): Movement Assessment Battery for Children(-2); MCT: motor control test for reactive balance control; MIT: motor imagery training; MPST: Muscle Power Sprint Test; NA: Not available; NAG: no-active video games; NCT: non-control trial; NTT: Neuromotor Task Training; PAC: Preferences for Activities of Children; PACER: Progressive Aerobic Cardiovascular Endurance Running; PCERT: Pictorial Children's Effort Rating Table; PE: physical education; PEGS: Perceived Efficacy and Goal Setting system; PMC: Perceived Motor Competence; PMT: Perceptual-motor therapy; PSDQ: Physical Self-Descriptive Questionnaire; RCT(-CO): randomized-control trial (cross over); SCAS: Spence's Child Anxiety Scale; SDQ: Strengths and Difficulties Questionnaire; SISST: Sensory Input Systems Screening Test; SOT: Sensory Organization Test; SPC: self-perceived physical competence; SPPC: Self Perception Profile for Children; TBCT: trampoline balance circuit training; TD: typical development; TGMD-2: Test of Gross Motor Development-2nd Edition; PSDQ: Physical Self-Descriptive Questionnaire; QNST-2: Quick Neurological Screening Test 2; UST: Unilateral Stance Test; VMI: Visual-Motor Integration Test.GH.

classified at the level of body function (e.g., postural sway, heart rate or maximum oxygen consumption) and participation (e.g., participation in daily living activities, sport and recreation). In these classifications, the outcome measures were more diverse (See also Table 2 for all outcome measures).

2.2. Data extraction and assessment of study validity

2.2.1. Selection of studies

Two review authors (BSE and VQ) independently screened titles and abstracts for potential inclusion from the literature searches and coded them as either 'retrieve' (eligible or potentially eligible/unclear) or 'do not retrieve' (clearly not eligible). To avoid any conflict of interest due to authorship, we had two separate teams rate studies and extract data (SV/HP and BSE/VQ). Each pair of reviewers independently screened each retrieved, eligible full-text publication (based on abstract) and recorded reasons for each "not retrieve" study. Any disagreement was resolved through discussion. Where a common dataset was reported in two or more separate papers, study information (like sample size) was pooled across papers. We recorded the selection process and summarized the information in a PRISMA flow diagram (Moher et al., 2009; See Fig. 1). The two pairs of review authors (BCM/VQ and SV/HP) independently extracted data from the included studies (number of participants, sex ratio, DSM criteria used, diagnostic tests and cut-off used, means and SD on the outcomes).

2.2.2. Strength of evidence

The following three parameters were used to determine the strength of evidence for a given intervention approach: (1) the *quality* of individual studies, (2) *quantity* of studies, and (3) *consistency* of outcomes across all reviewed studies.

(1) *Study Quality*. The quality of individual studies (or Level of Evidence—LOE) was assessed in two steps: first, the integrity of design features, and second, a rating of the *risk of bias* that may have contributed to an outcome. To rate the quality of the study design, we used a revised grading system for recommendations in evidence-based guidelines, which not only takes the design but also the risk of bias into account (See Table 1 adapted from Research System Agency for Health Care Policy; Harbour & Miller, 2001).

Since many of the studies in this review were clinical studies without randomization, we added the term, *controlled clinical trial* to the rating pro forma to denote non-randomized studies comparing two interventions, or comparing intervention and non-intervention groups of children with DCD.

Each study was reviewed for risk of bias by at least two experts in the field (BSE, RB, VQ, HP, SV, PW) who independently rated and assigned a 1, 2 or 3 for design quality using the modifiers shown in Table 1 (adding + or − signs to the rating), which is further explained in Tables 3a and 3b. Disagreements between raters were discussed and resolved through consensus involving a third rater. For randomized controlled trials, low overall risk of bias was determined when there was random sequence generation and blinded outcome assessment, and no other items had a high risk of bias. Since it was not possible to keep training personnel blind to the motor intervention, this aspect of design did not contribute to the risk scores. For the case-control studies and controlled clinical trials, we re-worded items 1–3 of Table 1 and rating scale (see Table 3b).

A potential selection bias in DCD research concerns whether or not children are referred for treatment by a professional clinician. This issue presents a possible confound when studies are compared (Geuze et al., 2015) and may hamper generalization of the results. For this reason, referral source was examined. In addition, we recorded how (non-DCD) children were assessed as being typically developing. Overall, studies that met 4 or fewer of the 7 criteria or had a serious flaw were rated as having high risk of bias.

(2) *Study Quantity*. The second parameter used to determine strength of the evidence was *quantity*, defined by the number of studies of a given type, and the number and type of participants included in those studies (See Tables 2 and 4).

(3) *Consistency of Outcomes*. The final parameter, *consistency*, was the extent to which findings are similar between different studies of the same type of intervention. We rated consistency as *high* when most studies (> 50%) found similar or at least coherent results, and *low* when considerable variation existed between study findings.

2.3. Data extraction and management

The outcomes of interest for the selected studies are listed in Table 2. We used a customized Excel™ spreadsheet to record study characteristics and outcome data (Blank et al., 2012). Study characteristics were as follows:

Population description: Number of participants, mean age, age range, gender, diagnostic criteria, motor test used, co-occurring diagnosis.

Methods: study design, total duration of study, frequency and duration per session.

Interventions: Intervention approach used, comparison intervention, or control. Each intervention was classified broadly as described above in a Body Function-, Activity- and Participation-oriented approach.

Outcomes: Three aspects were noted: the times the outcome measures were administered (pre, post and follow up); the specific measures (classified according to the ICF categories), short description of the conclusions.

2.4. Effect size estimates

Effect sizes (ES) are reported to aid comparisons of treatment efficacy across studies and between different approaches, and to inform power analyses in future work. Effect sizes were calculated to index the magnitude of pre-post differences for a given treatment group, independent of results for non-treatment DCD comparison groups. The index used was Cohen's *d*, corrected for sample size (*dc*); means and pooled *standard deviations* (SD) for pre- and post-test scores were used when reported. The magnitude of effects on norm-referenced tests were interpreted using the conventions of Cohen: small = 0.2, medium = 0.5, and large = 0.8 (Cohen, 1988).

2.5. Study inclusion

Initially 1313 studies were identified from the computerized database search. After deleting duplicates and applying inclusion and exclusion criteria, 327 papers were retrieved (see Fig. 1). After reading the abstracts, 42 papers were selected for full review; of these, 30 reported an evaluation of some kind of motor-based intervention. Characteristics of these 30 included studies are shown in Table 2.

Eight additional studies (Bonney, Jelsma, Ferguson, & Smits-Engelsman, 2017a; Jarus et al., 2015; Jelsma, Ferguson, Smits-Engelsman, & Geuze, 2015; Jelsma, Smits-Engelsman, Krijnen, & Geuze, 2016; Miles, Wood, Vine, Vickers, & Wilson, 2015; Snapp-Childs, Mon-Williams, & Bingham, 2013; Wood et al., 2017; Zamani, Fatemi, & Soroushmoghadam, 2015) not included in these 30, were experimental studies of motor learning processes, and are grouped in Table S2 non-included studies, together with one pharmacological study (Bart, Daniel, Dan, & Bar-Haim, 2013).

There were six notable exclusions: One study of children with "low motor competence" (not DCD) failed to include motor outcomes (McIntyre, Chivers, Larkin, Rose, & Hands, 2015); a paper that analyzed data from a study that appeared in the earlier review, examining performance strategies used by the child (Hyland & Polatajko, 2012) and a paper using data from an earlier study to examine why an active video game (AVG) intervention was ineffective (Howie, Campbell, Abbott, & Straker, 2017). Both Bonney et al. (2017a) and Wood et al. (2017) compared different instruction methods (variable vs. repetitive AVG training, and quiet eye training vs. watching an expert model, respectively), informing what might be effective ways to instruct children with DCD. Finally, Camden et al. (2016) investigated the impact of an evidence-based online module on perceived knowledge and skills of parents of children with DCD, and its behavioral/health outcomes.

For the quantitative evaluation, 19 data sets reporting standardized motor outcomes were available.

Table 3a
Risk of bias for the 10 data sets with RCT design (For interpretation of the references to colour in this Table, the reader is referred to the web version of this article.).

Primary Author	Year	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	LOE RCT
Au	2014	green	green	red	green	green	green	red	2	1+
Coetzee	2013	green	red	red	green	green	green	green	2	1+
Fong (2)	2013/2012	green	red	red	green	red	yellow	green	3	1-
Fong (2)	2016	green	green	red	green	green	green	green	1	1++
Hammond	2014	green	red	red	yellow	green	green	green	2	1+
Kordi	2016	green	green	red	yellow	green	green	green	2	1+
Straker (3)	2015/2016	green	red	red	yellow	green	yellow	green	3	1-
Thornton	2015	green	red	red	green	green	green	green	2	1+
Tsai	2012	red	red	red	red	green	green	green	3	1-
Wilson	2016	green	green	red	green	green	green	green	1	1++

RCT	Randomized Controlled Trials (red negative, yellow not mentioned, green Ok)
Q1	Random sequence generation
Q2	Allocation concealment
Q3	Blinding of participants and personnel
Q4	Blinding of outcome assessment, blind testers
Q5	Incomplete outcome data, lost in follow up
Q6	Selective outcome reporting, and other possible bias
Q7	Controls were sampled from a comparable population that gave rise to the DCD cases
Q8	What is the probability that the found relationship is causal? 1 = high probability causal (6 or 7 items positive), 2 = moderate probability (4–5 items), 3 = a significant risk that the relationship is not causal (3-1 items).
LOE	Up and downgrading of level 1 based on total evaluation including sample size.

Table 3b
Risk of bias for the 11 data sets with CCT design (For interpretation of the references to colour in this Table, the reader is referred to the web version of this article.).

Primary Author	Year	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	LOE CCT
Cacola	2015	red	red	green	yellow	green	green	green	3	2-
Farhat (2)	2015	green	green	green	yellow	green	green	green	2	2+
Ferguson	2013	green	green	green	green	green	green	green	1	2++
Ferguson	2015	green	green	green	green	green	green	red	2	2+
Giagazoglou	2015	green	yellow	green	yellow	green	yellow	green	3	2-
Jelsma	2014	green	green	green	green	green	green	green	1	2++
Noordstar	2017	red	green	green	green	green	green	green	2	2 +
Smits-Engelsman	2015	red	green	green	green	green	yellow	green	2	2-
Smits-Engelsman	2017	red	green	green	green	green	green	green	2	2+
Tsai	2014	green	green	green	yellow	green	green	green	2	2+
Yu	2016	green	green	green	green	green	green	green	1	2++

CCT	Controlled clinical trials, red negative, (yellow not mentioned, green Ok).
Q1	Is confounding of the effect of intervention likely in this study?
Q2	Did the authors use an appropriate analysis method that adjusted for all the critically important confounding domains?
Q3	Were confounding domains that were adjusted for measured validly and reliably by the variables available in this study?
Q4	Blinding of outcome assessment, blind testers?
Q5	Incomplete outcome data, large lost in follow up (> 20%)
Q6	Selective outcome reporting, and other possible bias
Q7	For (case-control) studies it is important to know if the controls were sampled from a comparable population
Q8	What is the probability that the found that the relationship is causal? 1 = high probability relation is causal (7), 2 = moderate probability (6-5 items positive), 3 = a significant risk that the relationship is not causal (4 or less items positive)
LOE	Up and downgrading of level 2 based on total evaluation (sample size, population selection)

3. Results

Results are presented in two main sections. First, we describe the general characteristics of the studies, including design. Second, we report results of the different approaches to intervention.

3.1. Study characteristics and design

Meeting inclusion criteria were 30 studies including a total of 807 participants with DCD (range 4–12 years of age) of which 509 received interventions and the rest received usual care or no intervention. No studies with adolescent or adult participants were found. Of these 30 studies, five papers reported data on the same set of participants in another paper (Farhat et al., 2015; Farhat et al., 2016; Fong, Guo, Cheng et al., 2016; Fong, Guo, Liu et al., 2016; Fong, Chung, Chow, Ma, & Tsang, 2013; Fong, Tsang, & Ng, 2012; Howie et al., 2017; Straker et al., 2015; Larke, Campbell, Jensen, & Straker, 2015). With data pooled across those studies, a final group of 25 datasets were examined. Descriptive characteristics of these 25 datasets (including participant characteristics, recruitment, DSM criteria and cut-off values for inclusion) are shown in Table 2. While DSM criteria were cited frequently (22/25), in many cases it was not mentioned whether participating children had a clinical referral for intervention.

3.1.1. Design

Most datasets (21/25) used a two-group comparison design between experimental intervention group and a no-intervention control or a second intervention group (7) (Au et al., 2014; Cacola, Romero, Ibana, & Chuang, 2016; Ferguson, Jelsma, Jelsma, & Smits-Engelsman, 2013; Fong, Guo, Liu et al., 2016; Noordstar, van der Net, Voerman, Helders, & Jongmans, 2017; Smits-Engelsman, Jelsma, & Ferguson, 2016; Wilson et al., 2016). In most instances both groups were comprised of children with DCD (17 studies), and in some the control group comprised typically developing (TD) children (4). Six studies used a three-group comparison – where two groups were comprised of children with DCD and the third group was comprised of TD children.

Three studies used a pre-post design without control group (Ashkenazi, Weiss, Orian, & Laufer, 2013; Larke et al., 2015; Zwicker et al., 2015) and there were two case studies (Baldi, Nunzi, & Brina, 2015; Menz, Hatten, & Grant-Beuttler, 2013).

Ten data sets used an RCT and 11 a CCT design. The *quality* of these studies based on design and risk of bias is summarized in Tables 3a and 3b. Overall in three of the ten RCT's there was still a significant risk that the found relationship was not causal as was the case for two of the 11 CCT's. If we look at the experimental intervention (so not the control treatment) the ES of the RCT was higher (ES 1.31) than of the CCT (1.08).

In relation to the *quantity* of studies and *consistency* of outcomes across studies examined we found that 11/12 of the activity oriented 5/7 of the AVG and 5/5 of body function oriented interventions led to significant effects on standardized motor tests. Of the studies with significant effects, Noordstar et al. (2017) and Wilson et al. (2017) showed confidence intervals that crossed the zero effect line.

3.1.2. Outcome measures

The Movement Assessment Battery for Children Test (MABC-1 or 2) was used most frequently, both for participant selection (20 of 25 datasets) and outcome evaluation (16 of 25). A version of the Bruininks-Oseretsky Test of Motor Proficiency 2nd Edition (BOT-2) was used in six studies (Au et al., 2014; Fong, Guo, Cheng et al., 2016; Hammond, Jones, Hill, Green, & Male, 2014; Menz et al., 2013; Kordi, Sohrabi, Saberi Kakhki, & Attarzadeh Hossini, 2016; Smits-Engelsman et al., 2017). Jelsma, Geuze, Mombarg, and Smits-Engelsman (2014), Kordi et al., 2016 and Smits-Engelsman et al., 2017 used the MABC-2 for participant selection but also subtests of the BOT-2 for evaluation of the intervention. One study used the Test of Gross Motor Development-2nd Edition (TGMD-2) as an outcome (Yu et al., 2016).

Six papers (~20%) did not measure or report intervention effects on a standardized motor test, but rather used experimental tests and questionnaires (Fong, Guo, Cheng et al., 2016; Fong, Guo, Liu et al., 2016; Fong et al., 2013; Fong et al., 2012; Giagazoglou, Sidiropoulou, Mitsiou, Arabatzi, & Kellis, 2015; Zwicker et al., 2015). Baldi et al. (2015) reported outcomes on a standardized handwriting test. These seven studies were not included in the meta-analysis summarized in Table 4.

Parent and/or teacher reports of activity outcomes were gathered in a small number of studies (7). The Developmental Coordination Disorder Questionnaire (DCD-Q) was used in three studies and the Canadian Occupational Performance Measure (COPM) in the two Cognitive Orientation to Daily Occupational Performance (CO-OP) studies (Thornton et al., 2016; Zwicker et al., 2015). Other questionnaires assessing parent perception of change in their child's participation were used in rare cases (see Tables 2 and 5).

In four papers, postural sway was examined as an aspect of motor control, using the Sensory Organization Test (SOT) (Au et al., 2014; Fong, Guo, Cheng et al., 2016; Fong, Guo, Liu et al., 2016; Fong et al., 2013).

3.2. Results by intervention approach

The range of interventions and outcome measures reported in the included studies is displayed in Table 2. For the synthesis of results presented below, interventions were grouped in ICF terms according to the main orientation or target of intervention:

3.2.1. Body function oriented

Goal: improvement of body functions and prevention of significant deviation or loss of body function or structure, taking into account future health risks (WHO, 2001). Specific treatment modalities were: (a) Strength training; (b) Aerobic fitness training; (c) Selective muscle activation (Biofeedback), and (d) Visual training (Occulo-motor training).

3.2.2. Activity oriented

Goal: Improvement of the execution of a task or skill. This may involve removing the activity limitations that an individual may have in executing activities, taking into account the specific task and context. Training considers the common circumstances and environment where the activity will be performed after the intervention. Specific treatment modalities were: (a) Task oriented Intervention (Neuromotor Task Training; NTT/CO-OP);(b) General Skill Training; (c) Sport/Play related Skill Training; (d) Virtual Reality Training (Active computer games, Exergames).

3.2.3. Participation oriented

Goal: Improvement in the child's involvement in a real life situation. This will involve training in client-identified tasks of importance, removing any restrictions to participation, taking into account factors relating to the physical, social and cultural environment in which the child lives. To promote transfer of the intervention to real life situations, active involvement of the child, parents and/or teachers is needed.

3.2.4. Outcome measures

Table 2 shows what outcomes were assessed for each study. Two studies reported outcomes only on body functions level, 16 on body function and activity level (MABC-2 and BOT-2), and five on all 3 ICF levels (body function, activity and participation).

3.3. Treatment effects for the intervention approaches

The overall effect size on the standardized motor tests across intervention studies was large, $dc = 1.06$. Of the five studies that compared two interventions on standardized tests, effect sizes were higher for the experimental (1.11) compared with the control interventions (0.63). For more detail see Tables 2 and 4.

3.3.1. Effects on standardized measures of movement skill

Of the 19 studies (and 24 interventions) that used the MABC or other standardized tests (BOT-2 and TGMD − 2) as an outcome, the mean effect size was high but variable across studies ($M = 1.06$; range: 0.21–4.37). In 12 of the interventions, the observed effect was large (> 0.80), in five studies moderate (> 0.50), and in seven studies small or negligible (< 0.50). Of the latter, two studies failed to show a significant effect between pre and post values of the standardized motor test (Ferguson et al., 2013; Thornton et al., 2016). When compared across the main intervention types, the mean ES was 1.81 for body-function oriented approaches (Range from 0.60–4.37) and 0.96 for activity oriented (Range from 0.21–2.77) (see Table 4).

3.3.2. Effects on validated questionnaires measuring motor function

Effect sizes against these standardized questionnaires are shown in Table 5, ranging from negligible to high, depending on the measure. The Thornton et al. (2016) study provides a good example of outcomes at different levels of the ICF: while children showed no improvement on the MABC, they wrote faster after intervention and parents (and the children) perceived changes in participation. Similarly, Zwicker et al. (2015) examined the effect of a small-group CO-OP intervention on a broad range of outcomes. Large effects were shown on the COPM performance and satisfaction (2.16 and 2.40) but no significant changes on the other questionnaires.

3.3.3. Intensity of the intervention

The mean duration of the intervention was 671 min (median 540, range 120–2400 min). Median frequency was 1.5 times per week (1–5), over 9 weeks (4–18) and 12 sessions (5–48). One half of the interventions were administered only once per week. To test the impact of treatment dose, we calculated correlations between effect size (ES) and the total duration of the intervention (mins). A significant moderate correlation was found between ES on standardized tests and duration ($r_s = 0.58$, $p = 0.003$). For one to one interventions alone, this relationship was not significant ($r_s = 0.39$. $p = 0.34$), while for other types of training (AVG/groups based) the relationship was moderate ($r_s = 0.68$, $p = 0.003$). The two Tsai studies (Tsai, Wang, & Tseng, 2012; Tsai et al., 2014) were clearly the most intensive (2400 and 1500 min), followed by Farhat (Farhat et al., 2016; Farhat et al., 2015) and (Kordi et al., 2016) (both 1440 min). The Hammond study (Hammond et al., 2014), Smits-Engelsman, Jelsma, Ferguson, and Geuze (2015) and Smits-Engelsman et al. (2017) had shortest duration of training (120 and 200 min, respectively).

3.3.4. Group intervention

Of the 25 datasets only eight studies involved in one to one interventions and 11 used a (small) group delivery mode. The remaining six studies used active exergaming as home-based intervention or in small groups as supervised play (see Table 2). While group-based intervention may be more cost effective, no study provided a formal cost-benefit analysis.

Only one study (Cacola et al., 2016) examined the psychological experience and impact of working in groups, which is known to be of benefit in general development (Poulsen, Ziviani, Johnson, & Cuskelly, 2008). However, in addition to group size, other variables differed between comparison groups: the smaller group in the Cacola study was engaged in goal directed training, addressing goals chosen by the children, while the larger group was task oriented and involved different skills.

3.3.5. Virtual reality or active computer games

Playing AVGs was evaluated in seven studies of relatively small sample size ($n = 9$ to 56); all studies with the exception of Smits-Engelsman et al. (2017 were low in statistical power. In most cases, these AVG programs were implemented in a supervised school setting or as a supervised small-group intervention (4–6 students). While six of these studies showed positive treatment effects (Ashkenazi et al., 2013; Ferguson et al., 2013; Hammond et al., 2014; Jelsma et al., 2014; Smits-Engelsman et al., 2017; Smits-Engelsman, Jelsma et al., 2015) the effect sizes on standardized measures were mild to moderate at best (Mean ES = 0.68, range 0.30–0.96); only those of Ashkenazi et al. (2013) (0.96), and Smits-Engelsman et al. (2016) were of larger magnitude (0.79 and 0.94). Ferguson et al. (2013) and Smits-Engelsman et al. (2016) examined also effects of AVG at the impairment level: ESs ranging between 0.46 and 1.67 on anaerobic fitness (Ferguson et al., 2013; Smits-Engelsman et al., 2016).

Ashkenazi et al. (2013) used the DCD-Q (ES 0.81) and Hammond et al. (2014) the Client Satisfaction Questionnaire (CSQ) part quality and satisfaction for evaluation purposes with high effect sizes (ES 1.09 and 0.98). Interestingly, although children reported perceived improvements in their physical skills and 13 out of the 21 children started participating in a new sport (Straker et al., 2015), the intervention did not improve their objectively measured physical activity and sedentary time (Howie, Campbell, & Straker, 2016). In a further analysis of these results the authors examined possible causes for the lack of improvement and concluded that children may not have exposed themselves to games that challenged and improved skill deficits, resulting in a motivation-outcome tradeoff (Howie et al., 2017). Supervised use of AVGs has been recommended by Jelsma et al. (2015); the time children play games and the variety of choices should be monitored. There is some evidence that motor skills developed in the virtual reality environment transfer best to the real world when there is natural connection between the trained tasks and real world contexts (Bonney, Jelsma, Ferguson, & Smits-Engelsman 2017b; Smits-Engelsman et al., 2017). However, additional data is required to support this hypothesis and to determine the degree of specificity in learning.

3.3.6. Intervention effects on health related fitness outcomes

Fitness outcomes are salient to DCD because overweight and obesity are over represented in these children (Cairney et al., 2005;

Table 4
Author, test used, pre and post tests means, standard deviation, and effect size with 90% confidence intervals listed per approach for studies in which data from the MABC (1or 2) BOT (Short form of subtests) or TGMD-2 were available. Non-significant results on the standardized tests are marked with #. Confidence intervals crossing the no-effect limit (0) are printed bold.

Activity oriented	Pre Test mean	SD	Post Test mean	SD	n	Effect Size (d Cohen)	Lower Confidence Interval for ES	Bias corrected Effect Size (Hedges)	Upper Confidence Interval for ES	Standard Error of E.S. estimate
Ferguson et al., 2013. **NTT (MABC-2)**	4.3	1.0	8.7	2.5	27	2.30	1.69	2.27	2.84	0.35
Farhat et al., 2015. **Motor skills (MABC-2)**	17	4.5	8.1	3.5	14	2.21	1.36	2.14	2.92	0.47
Tsai et al., 2012. **Skill training: Soccer (MABC-1)**	19	4.8	13.5	3.3	16	1.34	0.67	1.31	1.95	0.39
Cacola et al., 2016. **TOT (MABC-2)**	2.5	3	20.1	19.6	11	1.26	0.44	1.21	1.97	0.46
Au et al., 2014 **TOT (BOT-SF)**	39.7	3.9	44.8	5.5	11	1.07	0.28	1.03	1.78	0.45
Cacola et al., 2016 **Goal directed training (MABC-2)**	3.2	3.1	15.4	16.5	13	1.03	0.31	1.00	1.68	0.42
Noordstar et al., 2017. **Usual care + perceived competence (MABC-2)**	3.1	1.5	4.2	2.3	11	0.57	**−0.17**	0.54	1.26	0.43
Noordstar et al., 2017. **Usual care (MABC-2)**	3.8	2.4	5.6	4.1	20	0.54	**0.00**	0.53	1.05	0.32
Wilson et al., 2016 **MI (MABC-1)**	19.5	7.6	15.8	6.5	12	0.52	**−0.18**	0.51	1.19	0.41
Wilson et al., 2016 **PMT (MABC-1)**	19.2	7.6	15.3	7.9	13	0.50	**−0.17**	0.49	1.14	0.40
Yu et al., 2016 **Error reduced learning (TGMD)**	16.8	5.17	19.0	7.9	22	0.33	**−0.19**	0.32	0.80	0.30
Thornton et al., 2016 **CO−OP (MABC-2)**	46.9	12.09	50.7	20.91	10	0.22	**−0.52**	0.21#	0.95	0.45
Ashkenazi et al., 2013 **(MABC-2)**	4.7	1.4	7.4	3.5	9	1.01	0.15	0.96	1.78	0.50
Smits-Engelsman 2017 (BOT Balance)	13.8	3.0	17.7	4.9	17	0.96	0.34	0.94	1.53	0.36
Smits-Engelsman et al., 2016**(MABC Balance)**	20.7	7.9	27.0	7.6	17	0.81	0.10	0.79	1.49	0.36
Straker et al., 2015 **AVG Larke 2015 AVG (MABC-2)**	8.1	8.2	17.7	14,9	21	0.80	0.26	0,78	1,31	0.31
Jelsma et al., 2014 **(MABC + BOT subtests)**	2.6	1.6	4.2	3.0	28	0.67	0.20	0.66	1.11	0.27
Ferguson et al., 2013 **AVG (MABC-2)**	5.3	1.5	6.1	2.83	19	0.32	**−0.22**	0.32#	0.85	0.33
Hammond et al., 2014 **AVG (BOT-SF)**	4.0	11.9	11.7	32.5	10	0.32	**−0.44**	0.30#	1.04	0.45
Coetzee & Pienaar, 2013 **Visuomotor (MABC-1)**	22.1	5.5	3.8	1.7	18	4.47	3.36	4.37	5.38	0.61
Tsai et al., 2014 **CRT (MABC-2)**	48.9	5.4	68.7	9.0	20	2.68	1.91	2.62	3.33	0.43
Au et al., 2014 **Core stability (BOT-SF)**	40.6	6.2	46.9	8.4	11	0.85	0.09	0.82	1.55	0.44
Kordi et al., 2016. **Strength Training (Mean BOT Balance)**	2.9	0.8	3.4	0.7	15	0.62	0.01	0.62	1.25	0.38
Fong, Guo, Cheng et al., 2016. **Body sway (MABC-1 subscore Balance)**	3.0	2.1	1.9	1.5	47	0.60	0.25	0.60	0.94	0.21

Table 5
Studies that used validated questionnaires. Bold values indicate lower score at post test.

Study	Questionnaires	ES difference pre post
Ashkenazi 2013 AVG	DCD-Q	0.81
Au et al., 2014 Core training	SQT	0.00
Au et al., 2014 TOT	SQT	0.63
Cacola et al., 2016 TOT	DCD-Q, PAC, SDQ, CSAPPA, **SCAS**	0.59, 0.50, 0.48, 0.05, **−0.33**
Cacola et al., 2016 Goal oriented	DCD-Q, PAC, SDQ, CSAPPA, SCAS	0.08, 0.21, 0.19,0.18, 0.66
Hammond et al., 2014 AVG	CSQ Ability CSQ Satisfaction	1.09, 0.98
Noordstar et al., 2017 TOT+	DCD-Q, SPPC part PAC and GSE	0.77, 0.75, 0.36
Noordstar et al., 2017 TOT	DCD-Q, SPPC part PAC and GSE	0.74, 0.63, 0,54
Straker et al., 2015 AVG	DCD-Q CRPS	0.14, 0.67
Thronton COOP	GAS	1.98
Zwicker 2015 COOP	COPM Performance, COPM Satisfaction, Cape Enjoy, Peg child, CSAPPA **Peg parent**	2.16, 2.40, 0.00, 0.22, 0.12, **−0.22**

For Abbreviations see Table 2.

Hendrix, Prins, & Dekkers, 2014). Four studies reported improvement on tasks measuring physical fitness (e.g., 6 min walk, sprinting). While targeting participation, a health promotion plan implemented in schools (Ferguson, Naidoo, & Smits-Engelsman, 2015) led to improved aerobic and anaerobic capacity and strength. In Farhat et al. (2015) eight weeks of activity oriented training improved explosive power, cardiorespiratory fitness, aerobic endurance and motor coordination. Fong et al.'s (2013) Taekwondo program showed increased isokinetic knee muscle strength after 8 weeks of training. Running and agility also improved after 6 weeks of exergaming (Jelsma et al., 2014). The largest improvement on fitness measures was seen in the only study that was body-function oriented, which involved intensive endurance training (Tsai et al., 2014: 3 × 50-min sessions per week over 16 weeks).

Seven papers (Au et al., 2014; Farhat et al., 2016; Farhat et al., 2015; Ferguson et al., 2013; Ferguson et al., 2015; Fong et al., 2013; Smits-Engelsman et al., 2017), reported positive effects on strength, despite not targeting it specifically. Improvements were noted in isokinetic strength (Fong et al., 2013), functional strength (Ferguson et al., 2013; Ferguson et al., 2015; Smits-Engelsman et al., 2017) and BOT scores (Au et al., 2014). The largest increase in isometric leg muscle strength (ES 1.95) was seen in a program that specifically targeted strength, administered using two 60-min sessions per week over 12 weeks (Kordi et al., 2016).

Overall, a variety of motor interventions – whether Task oriented Training, General Skill Training, Sport/Play related Skill Training – led to moderate-to-strong improvements on fitness metrics, and associated changes in movement skill.

3.4. Intervention studies comparing two or more treatments

Six studies compared two or more different forms of intervention (Table 2). For five of these studies, we could calculate the effect size for the *difference* between treatments on standardized tests (Au et al., 2014; Cacola et al., 2016; Ferguson et al., 2013; Noordstar et al., 2017; Wilson et al., 2016); all involved primary-school aged children with comparable severity of motor impairment (aged 6–12 years with DCD < 16th on the MABC) and relatively short duration training (5–10 weeks). All studies (except the Wii group in Ferguson et al. (2013) reported positive effects for a range of activities- measured on standardized tests (MABC-2 or BOT-2); effect sizes were generally moderate to large (d = 0.49–2.27).

The RCT of Au et al. (2014) showed that activity oriented training and a core stability program yielded comparable (positive) effects on the BOT-2. Accordingly, the ES of the *difference* on the BOT-2 between groups was negligible, 0.122; Number to treat (NT) = 14.55 showed the difference lacks clinical relevance. However, the composite equilibrium score on the Sensory Organization Test (SOT) was significantly improved in the activity oriented group, only. The activity oriented program was broad-based, targeting functional tasks that involved body stability (e.g., standing) and body transport (e.g., walking, running, jumping, etc.), plus variations in task complexity/difficulty.

In the CCT of Ferguson et al. (2013), NTT showed large improvements on the MABC-2 (ES −2.3, NT 1.11), while that for Wii training was small (ES −0.32, NT 5.58). The effect size of the *difference* between the two groups was large 1.86 (NT 1.23), in favor of NTT. Differences in the magnitude of effects were most pronounced on manual dexterity and balance.

Cacola et al. (2016) showed stronger effects for one activity oriented program (conducted in a single group of 11; ES = 1.56, NT 1.37) compared with another activity oriented program (goal oriented approach; conducted in small groups), where skills were self-selected (ES = 1.24, NT 1.61). The effect size of the *difference* between the two groups was moderate, 0.488 (NT 3.7). Of note, children reported higher anxiety and less enjoyment in the larger group intervention.

The RCT by Wilson et al. (2016) was a replication and extension of an earlier study (Wilson, Thomas, & Maruff, 2002). This new study included a group of children with DCD, while the earlier study had children of below-average motor skill. Both studies compared Motor Imagery (MI) training, perceptual-motor training (PMT) and wait-list control. MI training consisted of: (i) video observation of skilled peers performing fundamental motor skills, (ii) mental reproduction of the observed movement from a 3rd-person perspective, and (iii) internal simulation from a 1st-person perspective. The PMT consisted of various perceptual-motor activities tailored to the needs of the individual child. Improvements on the MABC-1 were comparable between treatment groups (0.51, and 0.49 for MI and PMT, respectively NT 3.5), while no change was evident for the wait-list group (ES 0.15).

The Noordstar study compared usual care with and without add-on perceived competence training using verbal feedback

(Noordstar et al., 2017). Both interventions yielded similar positive results for self-perception of motor ability and for movement skills and with moderate effect sizes (ES 0.54 and 0.53, NT 3.4). It is clear that this difference between the interventions lacks clinical relevance. Importantly, this study is one of the few that re-evaluated the children and showed that after three months gains remained.

The balance training program of Fong, Guo, Cheng et al. (2016) and Fong, Guo, Liu et al. (2016) targeted the impairment level, designed to enhance balance strategies in children with DCD. The Functional Movement Training (FMT) group used biofeedback from EMG activation while performing MABC-1 balance items. A second treatment program involved individual strength/resistance training of the legs. Both programs improved equilibrium scores on the SOT, and on various aspects of leg strength and power. Improvement was maintained after 6 months in the FMT group. No comparisons were made between these groups on a standardized motor test, pre and post intervention.

4. Discussion

Children with DCD are generally referred to pediatric physical and occupational therapists, who use an array of therapeutic approaches to address the functional problems. Commonly used are body function oriented and activity oriented approaches. Since the earlier recommendation for interventions for children with DCD (Blank et al., 2012), many new studies have been published in this field. Unlike other reviews, we have included here all motor-based intervention studies published between January 2012 and February 2017, independent of design (i.e., case-study to RCT); studies of varying rigor and complexity have been included.

Including different designs in our review (and thereby expanding the number of eligible studies) has the potential to introduce sources of error associated with uncontrolled variables. However, this is tempered by presenting ratings of the risk of bias (aka quality of the evidence) in both RCTs and CCTs. One major advantage of including a larger sample of studies is that corroborating results greatly reduce the chance of spurious findings. Because the effect sizes we report are independent of results for non-treatment (DCD) comparison groups, these estimates may be inflated. In addition, a range of factors may promote motor skill development, which are not controlled for in the evaluation of the studies (e.g., spontaneous development, extra attention, positive regard, or practice effects).

4.1. General trends

The review reports on 30 new intervention studies, addressing 25 datasets conducted between January 2012 and February 2017 (an average of five studies per year). These figures underline some of the challenges in conducting intervention studies, particularly large-*N* and RCTs. Nonetheless, the body of this work is instructive, and has revealed some compelling trends in the research over recent years. Overall the design of the studies was moderate to good (see Tables 2, 3a and 3b) and data on several approaches increased (e.g. Sport/Play related Skill Training, Virtual Reality Training).

Of the three parameters used to determine the strength of evidence, we found that the *quantity* and *quality* was moderate to good (i.e., risk of bias was high in 5/21 studies). *Consistency* of outcomes across all reviewed studies was very good with 21/24 interventions showing significant improvement on standardized motor performance tests.

There was a definite trend towards more activity oriented training that addressed specific skills needed for play and sports participation. However, no comparison study tested whether interventions actually led to more participation in physical activity, sports or other forms of active play, nor tested effects on well-being. Also, no study tested whether intervention effects differed as a function of age, severity or co-occurring disorders.

There have been some prominent changes in the type of training since 2011 with group-based intervention, other work using AVGs, and fitness-based programs adding to the treatment landscape. Like earlier reviews, however, the most frequently reported type of intervention was activity oriented (12/24) (Table 4). Importantly, most studies show positive treatment effects, primarily on measures at the activity level of the ICF (esp. movement skill and activities requiring physical fitness) but also at impairment level (strength, cardiorespiratory function (CRF), body sway).

4.2. Activity oriented approaches are generally effective

Whereas the earlier clinical guidelines (Blank et al., 2012) reported a dominance of activity oriented approaches that were designed to promote movement skill, in recent years we see that improvement in body function has also been targeted, e.g., AVG to improve balance (Jelsma et al., 2015) and General Skill Training to improve strength or endurance (Farhat et al., 2015).

Taken together, the review identified two forms of activity oriented interventions: task oriented approaches designed to address (specific) real world goals selected by the child (Cacola et al., 2016; Ferguson et al., 2013; Thornton et al., 2016; Zwicker et al., 2015) and generic activity oriented approaches designed to teach a set of general or sports/play related motor skills e.g. soccer: Tsai et al. (2012); Taekwando: Fong et al. (2012, 2013); health promotion: Ferguson et al. (2015).

Activity-oriented approaches (like NTT) that focus on task-specific skills showed consistent improvements not only on activity based outcomes but also on body function. This finding is corroborated by other, recent reviews. Lucas et al. (2016) reviewed nine RCT's that evaluated interventions that aimed to improve gross-motor performance in children with neurodevelopmental disorders (Cerebral Palsy and DCD). They found that some interventions with a task oriented framework improved gross-motor outcomes; however, high quality intervention trials were not well represented. Additionally, based on a systematic review and meta-analysis of 29 articles on physical therapy, Offor, Williamson, and Cacola (2016) concluded that task oriented approaches (NTT) and motor training programs from traditional and contemporary physiotherapy (PT) frameworks are beneficial for children with DCD. Interventions based on PT motor skills training and NTT are effective for gross-motor problems. NTT is also effective for fine-motor problems (Offor et al., 2016). The recent meta-analysis of 6 studies by Miyahara et al. (2017) reported that task-oriented interventions improved motor performance more compared to no intervention. Finally, in a meta-analysis of nine RCTs in DCD, Preston et al. (2017) showed large ESs for 'Neuromotor Task Training', 'Task oriented Motor Training' and 'Motor Imagery + Task Practice Training'.

For the CO-OP approach (focusing mainly on cognitive strategies to facilitate skill acquisition), a controlled trial showed positive gains on the Goal Attainment Scale in the intervention compared to no intervention group (Thornton et al., 2016) and pre-post comparison on questionnaires measuring performance and satisfaction (COPM) (Zwicker et al., 2015); however, neither study showed change on standardized measures of movement skill. In their narrative review on the effect of CO-OP, Anderson, Wilson, and Williams (2017) included six articles, no analysis of improvement on motor tests was reported. They concluded that the CO-OP approach, when administered in a group format, has the potential to benefit children with DCD in both physical and psycho-social domains. However, more controlled studies are needed that confirm the effectiveness of CO-OP on clinical tests of motor skill and physical participation (Anderson et al., 2017).

4.3. Active computer games as a useful adjunct

Use of AVGs has steadily grown as a popular form of entertainment and play, and are finding a place in movement rehabilitation across a range of conditions. The results of a recent review (Bonnechere, Jansen, Omelina, & Van Sint Jan, 2016) show that in most cases, the introduction of AVG training in physical rehabilitation offered similar results to conventional therapy. The evidence thus far shows a positive effect of AVGs on motivation and engagement in rehabilitation (Lohse, Shirzad, Verster, Hodges, & Van der Loos, 2013). Although the use of AVGs for children with DCD is relatively new, efficacy has been tested in other health conditions (Cerebral Palsy, Stroke, Parkinson's Disease). AVGs have numerous advantages, such as preventing monotony and boredom, increasing motivation, providing direct feedback, and allowing double-task training (Bonnechere et al., 2016). On the other hand there are some concerns with AVGs. Although AVGs aim to activate children by doing games in sport related tasks, they may increase time spent playing computer games in general, leading to less active outside play.

AVG-based training in DCD shows promising effects, but the issue of transfer to everyday performance and participation is an unanswered question. It has recently been shown that AVGs lead to moderate improvement on balance tasks (Ashkenazi et al., 2013; Bonney et al., 2017a; Jelsma et al., 2015; Smits-Engelsman et al., 2017; Smits-Engelsman, Jelsma et al., 2015) in DCD, and that children also improved on more functional tasks like standing up from a chair and going up and down stairs (Bonney et al., 2017b; Smits-Engelsman et al., 2016). Before we can make an evidence-based recommendation for the impact of AVGs on participation in sport and outside play, studies evaluating this aspect are needed. Importantly more insight is needed on mechanisms of transfer from the virtual to real world, and on the limits of such interventions.

Taken together including AVGs as an adjunct to more mainstream intervention is worth considering. Although mean effect size is moderate (ES 0.68), it was shown the children with DCD enjoy the games, which can improve engagement in the process of intervention and, therefore, may be a better alternative to more sedentary games.

An important difference between AVGs and regular physical or occupational therapy is that children learn motor skills more implicitly during gaming since no formal instruction is provided. The relative efficacy of implicit and explicit approaches to learning is an area of future investigation. Finally, although supervision is needed, the hours that have to be put in by a professional are relatively few. Exergaming may be a convenient supplement to more tailored intervention. The relationship between improved AVG performance and engagement in physical activity (Participation) is in need of further investigation.

4.4. Body-function oriented training combined with activities

Body-function oriented therapies are now commonly combined with other forms of activity-based therapy. Most studies focusing on strength or visual training, for instance, were combined with some more functional tasks (e.g., Fong, Guo, Cheng et al. (2016) combined power training with Functional movement training; Coetzee & Pienaar (2013) combined reading with walking or jumping). Combined approaches such as these may have improved the level of transfer. The efficacy of body-function oriented approaches varies considerably and there remains a need to validate transfer to multiple ICF levels.

4.5. Intervention in small groups

Interpreting results for group-based intervention is not straightforward because differences in protocol exist other than group format vs. not. Overall, group-based intervention (ES 1.46) and individual-based training (ES 1.05) both produced large effects on motor performance. The strong effect for group-based intervention suggests that it may be a good option where the cost of treatment is an issue. Recommendations on the ideal group size cannot be determined based on the data but we know that groups of between 4 and 6 children have been used, are manageable, and effective with one therapist and optional assistant (Cacola et al., 2016; Farhat et al., 2015; Ferguson et al., 2013; Zwicker et al., 2015). Indeed, small groups enable instructors to move easily between participants and to monitor both group dynamics and individual progress. It is possible that children with very poor motor skill may feel more anxious in a larger group as was found in one study (Cacola et al., 2016). These same children did, however, improve their ability to deal with peer problems, which is a very useful life skill. Results also showed that choosing your own goals and that playing together may reduce performance anxiety and encourage task engagement (Cacola et al., 2016; Zwicker et al., 2015). Moreover, playing games (both on the computer and real) in groups may improve adherence, both in the short- and longer-term (Ferguson et al., 2013;

Jelsma et al., 2014). However, controlled studies that compare group-based and individual intervention on motor outcomes and psychological factors are needed.

4.6. Intervention to improve health-related physical fitness has a positive impact

To minimize the risk of long-term health problems associated with poor motor coordination (e.g., weight gain, physical inactivity, cardiovascular problems), promotion of an active lifestyle and training of skills needed in sports (e.g., agility, ball skills) is recommended. Studies provide consistent evidence that activity oriented training, like NTT and Sport/Play related Skill Training, and Virtual Reality Training involving exergames can all improve basic physical condition and functional strength needed in daily activities and can be integrated into intervention plans. However the real effects of these approaches on daily activity has not been examined.

4.7. Toward a standard framework for reporting trials

Interventions to improve motor performance in DCD have many components and vary in type, intensity, duration, and frequency. The Consolidated Standards of Reporting Trials (Consort, 2010) states that precise information should be given about the intervention but a number of studies in this review were hard to classify. In future, we strongly recommend that all authors use a comparable framework like the Template for Intervention Description and Replication (TIDieR) checklist (Hoffmann et al., 2014). This would facilitate replication studies and inter-study comparison, enabling reviewers to unpack often heterogeneous results.

4.8. Aspects of dose and scheduling: lack of comparative data

Our review also aimed to examine the available information on optimal duration and frequency of therapy, and treatment indications for different sub-groups (e.g., children of different ages, socioeconomic status, and with co-occurring conditions). However, research bearing on these questions was lacking. There is a large gap in knowledge of how the choice of therapy can be optimized for individuals with DCD and co-occurring disorders in terms of dosage, timing, scheduling, and content. Although comorbidity is prominent in neurodevelopmental disorders (e.g Lingam, Golding, Jongmans, Hunt, Ellis, Emond, 2010), no study evaluated possible differences in effect or approach between groups of children with and without co-occurring disorders (e.g., DCD +/− ADHD). Co-occurring disorders may seriously impact outcomes and therefore deserve more attention in future research.

Training protocols showed much variability in scheduling and dose across studies. While the average duration was relatively short at around 9 weeks, the length of intervention varied between 4 and 18. The studies that were in the longer range (10–16 weeks) and more frequent (2–3 per week) were group-based programs targeting specific sport skills or general fitness (Soccer, Trampoline, Endurance training, Power training) (Fong, Guo, Liu et al., 2016; Tsai et al., 2012; Tsai et al., 2014). Scheduling and dose were broadly consistent with the goals of these programs. In particular, training fine-motor skills tends to be more time intensive than gross-motor. Although many of the programs of around 9 h total duration show good training effects on manual dexterity, handwriting seems more resistant to change over these timeframes (Baldi et al., 2015). Studies that compare different treatment approaches, different modes of delivery and their applicability to subgroups are much needed in this area. Only the study of Ashkenazi et al. (2013) studied preschool children (aged 4–6 years) and no intervention studies of adolescents and adults were retrieved.

A final question for future research concerns how the duration of practice sessions and total duration of therapy interact with the practice schedule adopted. Results from the motor learning literature suggest that a random practice order enhances motor learning more when compared with blocked practice (Shea & Morgan, 1979). For DCD, no studies have yet examined the level of learning transfer, nor compared different modes of instruction. For example, the addition of motor imagery and action observation (Adams, Lust, Wilson, & Steenbergen, 2014) might well complement other approaches to intervention. In one study, Yu et al. (2016) did test the effect of task oriented motor skill training using an error-reduced learning strategy, and Smits-Engelsman et al. (2016) and Bonney et al. (2017a), tested the effect of different AVG protocols. However, because group composition is not consistent across studies, the ability to draw strong inferences is reduced.

4.9. Quality of the studies and interpretation of the results

In short, our review confirms that children with the diagnosis of DCD should receive intervention. On valid and reliable norm-referenced tests, the overall effect size across studies was large (d = 1.06). However, there was considerable variation in the magnitude of effects. In 11 of the interventions, the ES was large (> 0.80), in eight studies moderate (> 0.50), and in five studies small or negligible (< 0.50). Of the latter, two failed to show a significant effect between pre- and post-test values on a standardized test (Table 4). In general, for any given approach to intervention, the magnitude of effect sizes did not differ greatly between RCTs and CCTs. Although results indicate that there is evidence that activity-oriented and body function oriented interventions can have a positive effect on motor function and skills, mixed methodological quality and large confidence intervals of some studies suggests that results should be viewed with caution.

Our analysis shows that to best evaluate treatment effects, measures at both the activity and participation levels should be used, providing a broader representation of the impact of intervention (Table 2, 4 and 5). Because mechanisms of transfer remain unclear, it is recommended that activity-oriented approaches be used, which, by definition, are aligned to real world activities that are of significance to the child. In addition, body function oriented approaches should target function(s) that most clearly support the activities of significance (e.g., running agility for a field sport).

For all interventions there remains a dire need for (learning) retention studies and analysis of how effectively learned skills and capacities can transfer to the activities of daily living and participation in sport and recreation. The ability to measure subtle change in children's capacity in activities of daily living (ADL) is vital for researchers and clinicians. New technologies (e.g., wearable sensors using accelerometers, bend sensors, Global Positioning System (GPS) tracking, exoskeletons, etc.) will improve our ability to track performance objectively over time and with greater precision.

Lastly, to make the interpretation of results easier for readers, we encourage authors to report effect sizes and their associated confidence intervals. Clinical significance metrics like the *minimal important difference* (MID) values or *smallest detectable difference* (SDD) are also valuable for clinicians and researchers alike.

4.10. Limitations

By including both RCTs and CCTs in our review, additional error variance is introduced when calculating mean ESs. In particular, factors that may promote motor development in children are not controlled for; as such, alternative explanations for observed effects are possible (e.g., spontaneous development, extra positive attention or retest effects). However, we have tempered our interpretation in a number of ways by: (i) estimating the risk of bias in both RCTs and CCTs, (ii) evaluating consistency of the results, and (iii) reporting not only if the intervention led to a statistically significant change but also the effect size and its confidence interval. The review showed that in most cases the true effect lay within an acceptable range, but for some cases these values crossed the zero effect line warranting some caution in the interpretation.

4.11. Implications for practice and conclusion

This update on the evidence for DCD intervention shows that there is consistency for the positive effect of activity-based interventions on a range of outcome variables: 11 of the 12 interventions evaluated showed significant improvements between pre- and post-test on validated motor batteries.

The general efficacy of activity oriented approaches, AVG and programs addressing body functions begs the question of the most cost effective approach. Cost-benefit analyses are needed to inform how finite resources for intervention are best spent in the context of rising health care costs. New data supporting the immediate benefits on performance of relatively short duration intervention, AVGs, and small group programs now prompt more rigorous RCTs with follow up to show sustained change rather than short-term performance gains.

The review reinforces the principle that training programs stay close to the tasks and circumstances needed in the child's everyday life. If the child is trained in tasks of everyday relevance, even relatively short periods of training can have a positive effect (around 9 weeks). Fine motor skills may take a little longer, but comparison studies between approaches for fine motor skills are absent. Future studies should also report on outcomes at the participation level as evidence of transfer from body function and activity level to the real world is sparse. Moreover long term effect or retention studies are needed since they are even more scant (Fong, 2016; Noordstar et al., 2017; Coetzee & Pienaar, 2013).

Another important new finding was the large number of studies that reported on effectiveness when programs were conducted in a small group format. However, we do not have sufficient evidence to make informed decisions on who is most likely to benefit. Studies on the motivational or emotional aspects are lacking. The fact that no differences in the magnitude of treatment effects were found between small group and one to one therapy could have implications for intervention services. Once children are deemed eligible for services in many countries, they are still placed on waitlists. Group intervention can improve access for many children and save resources, while one to one treatment tailored to the needs of the individual child is maintained. It has been shown in several studies that individual goals can still be addressed in small group programs (Ferguson et al., 2013; Zwicker et al., 2015).

New training formats (like augmented feedback, for example), new delivery modes and training schedules could be piloted based on the available evidence and then evaluated in new RCT's, which should include longer follow-up times. Additionally time-series analysis might be used to monitor learning effects over the duration of training (Damiano, 2014). Specific comparison studies are needed to determine the optimal learning and teaching approaches for (subgroups of) children and adults with DCD to be able to make better evidence based recommendations for the broad spectrum of individuals with DCD. So far no study compared whether children referred to a clinic performed differently to those selected only for research. Until then conclusions about effectiveness should be interpreted with care.

Whatever the intervention, the motor learning literature suggests that time on task (duration, repetition, intensity) and task salience are good predictors of progression in motor skill development (Kleim and Jones 2008). As such it is important to leverage opportunities for practice and generalization of skills by enlisting the support of parents, teachers, and significant others. Both activity oriented interventions, and body-function oriented interventions that are combined with functional tasks are suggested. Training everyday activities by targeting the weakest link in the activity chain, and programs that support learning of complex motor skills in areas of (self-selected) interest are important, enhancing the child's readiness and willingness to participate in life activities, improve fitness and prevent obesity.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ridd.2018.01.002.

References

Adams, I. L., Lust, J. M., Wilson, P. H., & Steenbergen, B. (2014). Compromised motor control in children with DCD: A deficit in the internal model?-A systematic review. *Neuroscience and Biobehavioral Reviews, 47*, 225–244. http://dx.doi.org/10.1016/j.neubiorev.2014.08.011.

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: American Psychiatric Association.

Anderson, L., Wilson, J., & Williams, G. (2017). Cognitive Orientation to daily Occupational Performance (CO-OP) as group therapy for children living with motor coordination difficulties: An integrated literature review. *Australian Occupational Therapy Journal, 64*(2), 170–184. http://dx.doi.org/10.1111/1440-1630.12333.

Ashkenazi, T., Weiss, P. L., Orian, D., & Laufer, Y. (2013). Low-cost virtual reality intervention program for children with developmental coordination disorder: A pilot feasibility study. *Pediatric Physical Therapy, 25*(4), 467–473. http://dx.doi.org/10.1097/PEP.0b013e3182a74398.

Au, M. K., Chan, W. M., Lee, L., Chen, T. M., Chau, R. M., & Pang, M. Y. (2014). Core stability exercise is as effective as task-oriented motor training in improving motor proficiency in children with developmental coordination disorder: A randomized controlled pilot study. *Clinical Rehabilitation, 28*(10), 992–1003. http://dx.doi.org/10.1177/0269215514527596.

Baldi, S., Nunzi, M., & Brina, C. D. (2015). Efficacy of a task-based training approach in the rehabilitation of three children with poor handwriting quality: A pilot study. *Perceptual and Motor Skills, 120*(1), 323–335. http://dx.doi.org/10.2466/10.15.PMS.120v15x5.

Bart, O., Daniel, L., Dan, O., & Bar-Haim, Y. (2013). Influence of methylphenidate on motor performance and attention in children with developmental coordination disorder and attention deficit hyperactive disorder. *Research in Developmental Disabilities, 34*(6), 1922–1927.

Blank, R., Smits-Engelsman, B., Polatajko, H., & Wilson, P. (2012). European Academy for Childhood Disability (EACD): Recommendations on the definition, diagnosis and intervention of developmental coordination disorder (long version). *Developmental Medicine and Child Neurology, 54*(1), 54–93.

Bonnechere, B., Jansen, B., Omelina, L., & Van Sint Jan, S. (2016). The use of commercial video games in rehabilitation: A systematic review. *International Journal of Rehabilitation Research, 39*(4), 277–290. http://dx.doi.org/10.1097/MRR.0000000000000190.

Bonney, E., Jelsma, D., Ferguson, G., & Smits-Engelsman, B. (2017a). Variable training does not lead to better motor learning compared to repetitive training in children with and without DCD when exposed to active video games. *Research in Developmental Disabilities, 62*, 124–136. http://dx.doi.org/10.1016/j.ridd.2017.01.013.

Bonney, E., Jelsma, L. D., Ferguson, G. D., & Smits-Engelsman, B. C. (2017b). Learning better by repetition or variation? Is transfer at odds with task specific training? *PUBLIC LIBRARY OF SCIENCE, 12*(3), e0174214. http://dx.doi.org/10.1371/journal.pone.0174214.

Cacola, P., Romero, M., Ibana, M., & Chuang, J. (2016). Effects of two distinct group motor skill interventions in psychological and motor skills of children with Developmental Coordination Disorder: A pilot study. *Disability and Health Journal, 9*(1), 172–178. http://dx.doi.org/10.1016/j.dhjo.2015.07.007.

Cairney, J., & Veldhuizen, S. (2013). Is developmental coordination disorder a fundamental cause of inactivity and poor health-related fitness in children? *Developmental Medicine & Child Neurology, 55*, 55–58. http://dx.doi.org/10.1111/dmcn.12308.

Cairney, J., 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 (London), 29*(4), 369–372 [PubMed PMID: 15768042].

Camden, C., Foley, V., Anaby, D., Shikako-Thomas, K., Gauthier-Boudreault, C., Berbari, J., & Missiuna, C. (2016). Using an evidence-based online module to improve parents' ability to support their child with Developmental Coordination Disorder. *Disability and Health Journal, 9*(3), 406–415. http://dx.doi.org/10.1016/j.dhjo.2016.04.002.

Cantell, M., & Crawford, S. G. (2008). Physical fitness and health indices in children, adolescents and adults with high or low motor competence. *Human Movement Science, 27*(2), 344–362.

Cantell, M. H., Smyth, M. M., & Ahonen, T. P. (1994). Clumsiness in adolescence: Educational motor and social outcomes of motor delay detected at 5 years. *Adapted Physical Activity Quarterly, 11*, 115–129.

Cantell, M., Kooistra, L., Cermak, S., & Larkin, D. (2002). Long-term outcomes of developmental coordination disorder. *Developmental Coordination Disorder,* 23–38.

Coetzee, D., & Pienaar, A. E. (2013). The effect of visual therapy on the ocular motor control of seven- to eight-year-old children with developmental coordination disorder (DCD). *Research in Developmental Disabilities, 34*(11), 4073–4084. http://dx.doi.org/10.1016/j.ridd.2013.08.036.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* New York: Routledge.

Consort (2010). *Consolidated standards of reporting trials* from http://www.consort-statement.org/consort-2010.

Damiano, D. L. (2014). Meaningfulness of mean group results for determining the optimal motor rehabilitation program for an individual child with cerebral palsy. *Developmental Medicine & Child Neurology, 56*(12), 1141–1146. http://dx.doi.org/10.1111/dmcn.12505.

Farhat, F., Masmoudi, K., Hsairi, I., Smits-Engelsman, B. C., McHirgui, R., Triki, C., & Moalla, W. (2015). The effects of 8 weeks of motor skill training on cardiorespiratory fitness and endurance performance in children with developmental coordination disorder. *Applied Physiology, Nutrition, and Metabolism, 40*(12), 1269–1278. http://dx.doi.org/10.1139/apnm-2015-0154.

Farhat, F., Hsairi, I., Baati, H., Smits-Engelsman, B. C., Masmoudi, K., McHirgui, R., ... Moalla, W. (2016). The effect of a motor skills training program in the improvement of practiced and non-practiced tasks performance in children with developmental coordination disorder (DCD). *Human Movement Science, 46*, 10–22. http://dx.doi.org/10.1016/j.humov.2015.12.001.

Faught, B. E., Hay, J. A., Cairney, J., & Flouris, A. (2005). Increased risk for coronary vascular disease in children with developmental coordination disorder. *Journal of Adolescent Health, 37*(5), 376–380.

Ferguson, G. D., Jelsma, D., Jelsma, J., & Smits-Engelsman, B. C. (2013). The efficacy of two task-orientated interventions for children with developmental coordination disorder: Neuromotor task training and nintendo wii fit training. *Research in Developmental Disabilities, 34*(9), 2449–2461. http://dx.doi.org/10.1016/j.ridd.2013.05.007.

Ferguson, G. D., Naidoo, N., & Smits-Engelsman, B. C. M. (2015). Health promotion in a low-income primary school: Children with and without DCD benefit, but differently. *Physical & Occupational Therapy in Pediatrics, 35*(2), 147–162. http://dx.doi.org/10.3109/01942638.2015.1009230.

Fong, S. S. M., Tsang, W. W. N., & Ng, G. Y. F. (2012). Taekwondo training improves sensory organization and balance control in children with developmental coordination disorder: A randomized controlled trial. *Research in Developmental Disabilities, 33*(1), 85–95. http://dx.doi.org/10.1016/j.ridd.2011.08.023.

Fong, S. S. M., Chung, J. W. Y., Chow, L. P. Y., Ma, A. W. W., & Tsang, W. W. N. (2013). Differential effect of Taekwondo training on knee muscle strength and reactive and static balance control in children with developmental coordination disorder: A randomized controlled trial. *Research in Developmental Disabilities, 34*(5), 1446–1455. http://dx.doi.org/10.1016/j.ridd.2013.01.025.

Fong, S. S., Guo, X., Cheng, Y. T., Liu, K. P., Tsang, W. W., Yam, T. T., ... Macfarlane, D. J. (2016). A novel balance training program for children with developmental coordination disorder: A randomized controlled trial. *Medicine (Baltimore), 95*(16), e3492. http://dx.doi.org/10.1097/MD.0000000000003492.

Fong, S. S., Guo, X., Liu, K. P. Y., Ki, W. Y., Louie, L. H. T., Chung, R. C. K., et al. (2016). Task-specific balance training improves the sensory organisation of balance control in children with developmental coordination disorder: A randomised controlled trial. *Scientific Reports, 6*(February), 20945. http://dx.doi.org/10.1038/srep20945.

Geuze, R. H., & Borger, H. (1993). Children who are clumsy: Five years later. *Adapted Physical Activity Quarterly, 10*, 10–21.

Geuze, R. H., Schoemaker, M. M., & Smits-Engelsman, B. C. (2015). Clinical and research criteria for developmental coordination Disorder—Should they Be one and the same? *Current Developmental Disorders Reports, 2*(2), 127–130.

Giagazoglou, P., Sidiropoulou, M., Mitsiou, M., Arabatzi, F., & Kellis, E. (2015). Can balance trampoline training promote motor coordination and balance performance

in children with developmental coordination disorder? *Research in Developmental Disabilities, 36*, 13–19. http://dx.doi.org/10.1016/j.ridd.2014.09.010.
Hammond, J., Jones, V., Hill, E. L., Green, D., & Male, I. (2014). An investigation of the impact of regular use of the Wii Fit to improve motor and psychosocial outcomes in children with movement difficulties: A pilot study. *Child: Care, Health and Development, 40*(2), 165–175. http://dx.doi.org/10.1111/cch.12029.
Harbour, R., & Miller, J. (2001). A new system for grading recommendations in evidence based guidelines. *British Medical Journal, 323*(7308), 334.
Hay, J. A., Hawes, R., & Faught, B. E. (2004). Evaluation of a screening instrument for developmental coordination disorder. *Journal of Adolescent Health, 34*(4), 308–313. http://dx.doi.org/10.1016/j.jadohealth.2003.07.004.
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. http://dx.doi.org/10.1111/obr.12137.
Hill, E. L., Brown, D., & Sorgardt, S. K. (2011). A preliminary investigation of quality of life satisfaction reports in emerging adults with and without developmental coordination disorder. *Journal of Adult Development, 18*(3), 130–134. http://dx.doi.org/10.1007/s10804-011-9122-2.
Hoffmann, T. C., Glasziou, P. P., Boutron, I., Milne, R., Perera, R., Moher, D., ... Michie, S. (2014). Better reporting of interventions: Template for intervention description and replication (TIDieR) checklist and guide. *BMJ, 348*, g1687. http://dx.doi.org/10.1136/bmj.g1687.
Howie, E. K., Campbell, A. C., & Straker, L. M. (2016). An active video game intervention does not improve physical activity and sedentary time of children at-risk for developmental coordination disorder: A crossover randomized trial. *Child Care Health and Development, 42*(2), 253–260.
Howie, E. K., Campbell, A. C., Abbott, R. A., & Straker, L. M. (2017). Understanding why an active video game intervention did not improve motor skill and physical activity in children with developmental coordination disorder: A quantity or quality issue? *Research in Developmental Disabilities, 60*, 1–12. http://dx.doi.org/10.1016/j.ridd.2016.10.013.
Hyland, M., & Polatajko, H. (2012). Enabling children with Developmental Coordination Disorder to self-regulate through the use of Dynamic Performance Analysis: Evidence from the CO-OP approach. *Human Movement Science, 31*(4), 987–998.
Jarus, T., Ghanouni, P., Abel, R. L., Fomenoff, S. L., Lundberg, J., Davidson, S., ... Zwicker, J. G. (2015). Effect of internal versus external focus of attention on implicit motor learning in children with developmental coordination disorder. *Research in Developmental Disabilities, 37*, 119–126. http://dx.doi.org/10.1016/j.ridd.2014.11.009.
Jelsma, D., Geuze, R. H., Mombarg, R., & Smits-Engelsman, B. C. M. (2014). The impact of Wii Fit intervention on dynamic balance control in children with probable Developmental Coordination Disorder and balance problems. *Human Movement Science, 33*, 404–418. http://dx.doi.org/10.1016/j.humov.2013.12.007.
Jelsma, D., Ferguson, G. D., Smits-Engelsman, B. C. M., & Geuze, R. H. (2015). Short-term motor learning of dynamic balance control in children with probable Developmental Coordination Disorder. *Research in Developmental Disabilities, 38*, 213–222. http://dx.doi.org/10.1016/j.ridd.2014.12.027.
Jelsma, L. D., Smits-Engelsman, B. C., Krijnen, W. P., & Geuze, R. H. (2016). Changes in dynamic balance control over time in children with and without Developmental Coordination Disorder. *Human Movement Science, 49*, 148–159. http://dx.doi.org/10.1016/j.humov.2016.07.003.
Kirby, A., Williams, N., Thomas, M., & Hill, E. L. (2013). Self-reported mood, general health, wellbeing and employment status in adults with suspected DCD. *Research in Developmental Disabilities, 34*(4), 1357–1364. http://dx.doi.org/10.1016/j.ridd.2013.01.003.
Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage. *Journal of Speech, Language, and Hearing Research, 51*(1), S225–39. http://dx.doi.org/10.1044/1092-4388(2008/018) PubMed PMID: 18230848.
Kordi, H., Sohrabi, M., Saberi Kakhki, A., & Attarzadeh Hossini, S. R. (2016). The effect of strength training based on process approach intervention on balance of children with developmental coordination disorder. *Archivos Argentinos de Pediatria, 114*(6), 526–533. http://dx.doi.org/10.5546/aap.2016.eng.526.
Larke, D., Campbell, A., Jensen, L., & Straker, L. (2015). Responsiveness of clinical and laboratory measures to intervention effects in children with developmental coordination disorder. *Pediatric Physical Therapy, 27*(1), 44–51.
Lingam, R., Golding, J., Jongmans, M. J., Hunt, L. P., Ellis, M., & Emond, A. (2010). The association between developmental coordination disorder and other developmental traits. *Pediatrics, 126*(5), 1109–1118. http://dx.doi.org/10.1542/peds.2009-2789.
Lohse, K., Shirzad, N., Verster, A., Hodges, N., & Van der Loos, H. F. (2013). Video games and rehabilitation: Using design principles to enhance engagement in physical therapy. *Journal of Neurologic Physical Therapy, 37*(4), 166–175. http://dx.doi.org/10.1097/NPT.0000000000000017.
Losse, A., Henderson, S. E., Elliman, D., Hall, D., Knight, E., & Jongmans, M. (1991). Clumsiness in children – do they grow out of it? A 10-year follow-up study. *Developmental Medicine & Child Neurology, 33*(1), 55–68. http://dx.doi.org/10.1111/j.1469-8749.1991.tb14785.x.
Lucas, B. R., Elliott, E. J., Coggan, S., Pinto, R. Z., Jirikowic, T., McCoy, S. W., & Latimer, J. (2016). Interventions to improve gross motor performance in children with neurodevelopmental disorders: A meta-analysis. *BMC Pediatrics, 16*(1), 193. http://dx.doi.org/10.1186/s12887-016-0731-6.
McIntyre, F., Chivers, P., Larkin, D., Rose, E., & Hands, B. (2015). Exercise can improve physical self perceptions in adolescents with low motor competence. *Human Movement Science, 42*, 333–343. http://dx.doi.org/10.1016/j.humov.2014.12.003.
Menz, S. M., Hatten, K., & Grant-Beuttler, M. (2013). Strength training for a child with suspected developmental coordination disorder. *Pediatric Physical Therapy, 25*(2), 214–223. http://dx.doi.org/10.1097/PEP.0b013e31828a2042.
Miles, C. a. L., Wood, G., Vine, S. J., Vickers, J. N., & Wilson, M. R. (2015). Quiet eye training facilitates visuomotor coordination in children with developmental coordination disorder. *Research in Developmental Disabilities, 40*, 31–41. http://dx.doi.org/10.1016/j.ridd.2015.01.005.
Missiuna, C., Gaines, R., Soucie, H., & McLean, J. (2006). Parental questions about developmental coordination disorder: A synopsis of current evidence. *Paediatrics & Child Health, 11*(8), 507–512.
Miyahara, M., Hillier, S. L., Pridham, L., & Nakagawa, S. (2017). Task-oriented interventions for children with developmental co-ordination disorder. *Cochrane Database Systematic Reviews, 7*, CD010914. http://dx.doi.org/10.1002/14651858.CD010914.pub2.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine, 6*(7), e1000097. http://dx.doi.org/10.1371/journal.pmed1000097.
Noordstar, J. J., van der Net, J., Voerman, L., Helders, P. J., & Jongmans, M. J. (2017). The effect of an integrated perceived competence and motor intervention in children with developmental coordination disorder. *Research in Developmental Disabilities, 60*, 162–175. http://dx.doi.org/10.1016/j.ridd.2016.12.002.
Offor, N., Williamson, P. O., & Cacola, P. (2016). Effectiveness of interventions for children with developmental coordination disorder in physical therapy contexts: A systematic literature review and meta-analysis. *Journal of Motor Learning and Development, 4*, 169–196.
Peters, J. M., Barnett, A. L., & Henderson, S. E. (2001). Clumsiness, dyspraxia and developmental co-ordination disorder: How do health and educational professionals in the UK define the terms? *Child Care Health Dev, 27*. http://dx.doi.org/10.1046/j.1365-2214.2001.00217.x.
Poulsen, A. A., Ziviani, J. M., Johnson, H., & Cuskelly, M. (2008). Loneliness and life satisfaction of boys with developmental coordination disorder: The impact of leisure participation and perceived freedom in leisure. *Human Movement Science, 27*(2), 325–343.
Preston, N., Magallon, S., Hill, L. J., Andrews, E., Ahern, S. M., & Mon-Williams, M. (2017). A systematic review of high quality randomized controlled trials investigating motor skill programmes for children with developmental coordination disorder. *Clinical Rehabilitation, 31*(July (7)), 857–870. http://dx.doi.org/10.1177/0269215516661014.
Rivilis, I., Hay, J., Cairney, J., Klentrou, P., Liu, J., & Faught, B. E. (2011). Physical activity and fitness in children with developmental coordination disorder: A systematic review? *Research in Developmental Disabilities, 32*(3), 894–910.
Schott, N., Alof, V., Hultsch, D., & Meermann, D. (2007). Physical fitness in children with developmental coordination disorder? *Research Quarterly for Exercise and Sport, 78*(5), 438–450.
Shea, J. B., & Morgan, R. L. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Learning, Memory and Cognition, 5*, 179–187.
Smits-Engelsman, B. C., Blank, R., van der Kaay, A. C., Mosterd-van der Meijs, R., Vlugt-van den Brand, E., Polatajko, H. J., & Wilson, P. H. (2013). Efficacy of interventions to improve motor performance in children with developmental coordination disorder: A combined systematic review and meta-analysis. *Developmental Medicine and Child Neurology, 55*(3), 229–237.
Smits-Engelsman, B. C., Jelsma, L. D., & Ferguson, G. D. (2017). The effect of exergames on functional strength, anaerobic fitness, balance and agility in children with and without motor coordination difficulties living in low-income communities. *Human Movement Science, 55*, 327–337. http://dx.doi.org/10.1016/j.humov.2016.07.006.

Smits-Engelsman, B. C., Jelsma, L. D., Ferguson, G. D., & Geuze, R. H. (2015). Motor learning: An analysis of 100 trials of a ski slalom game in children with and without developmental coordination disorder. *PUBLIC LIBRARY OF SCIENCE, 10*(10), e0140470. http://dx.doi.org/10.1371/journal.pone.0140470.

Smits-Engelsman, B. C., Magalhaes, L. C., Oliveira, M. A., & Wilson, P. H. (2015). DCD research: How are we moving along? *Human Movement Science, 42*, 289–292. http://dx.doi.org/10.1016/j.humov.2015.06.012.

Snapp-Childs, W., Mon-Williams, M., & Bingham, G. P. (2013). A sensorimotor approach to the training of manual actions in children with developmental coordination disorder. *Journal of Child Neurology, 28*(2), 204–212. http://dx.doi.org/10.1177/0883073812461945.

Straker, L., Howie, E., Smith, A., Jensen, L., Piek, J., & Campbell, A. (2015). A crossover randomised and controlled trial of the impact of active video games on motor coordination and perceptions of physical ability in children at risk of Developmental Coordination Disorder. *Human Movement Science, 42*, 146–160. http://dx.doi.org/10.1016/j.humov.2015.04.011.

Thornton, A., Licari, M., Reid, S., Armstrong, J., Fallows, R., & Elliott, C. (2016). Cognitive Orientation to (Daily) Occupational Performance intervention leads to improvements in impairments, activity and participation in children with Developmental Coordination Disorder. *Disability and Rehabilitation, 38*(10), 979–986. http://dx.doi.org/10.3109/09638288.2015.1070298.

Tsai, C.-L., Wang, C.-H., & Tseng, Y.-T. (2012). Effects of exercise intervention on event-related potential and task performance indices of attention networks in children with developmental coordination disorder. *Brain and Cognition, 79*(1), 12–22. http://dx.doi.org/10.1016/j.bandc.2012.02.004.

Tsai, C. L., Chang, Y. K., Chen, F. C., Hung, T. M., Pan, C. Y., & Wang, C. H. (2014). Effects of cardiorespiratory fitness enhancement on deficits in visuospatial working memory in children with developmental coordination disorder: A cognitive electrophysiological study. *Archives of Clinical Neuropsychology, 29*(2), 173–185. http://dx.doi.org/10.1093/arclin/act081.

Venetsanou, F., Kambas, A., Ellinoudis, T., Fatouros, I., Giannakidou, D., & Kourtessis, T. (2011). Can the Movement Assessment Battery for Children-Test be the gold standard for the motor assessment of children with Developmental Coordination Disorder? *Research in Developmental Disabilities, 32*(1), 1–10. http://dx.doi.org/10.1016/j.ridd.2010.09.006.

WHO (2001). *International classification of functioning, disability and health: ICF.* Geneva: World Health Organization.

WHO (2007). *International classification of functioning, disability and health: children and youth version: ICF-CY*. Geneva: WHO.

Wilson, P. H., Thomas, P. R., & Maruff, P. (2002). Motor imagery training ameliorates motor clumsiness in children. *Journal of Child Neurology, 17*(7), 491–498. http://dx.doi.org/10.1177/088307380201700704.

Wilson, P. H., Ruddock, S., Smits-Engelsman, B., Polatajko, H., & Blank, R. (2013). Understanding performance deficits in developmental coordination disorder: A meta-analysis of recent research. *Developmental Medicine and Child Neurology, 55*(3), 217–228.

Wilson, P. H., Adams, I. L. J., Caeyenberghs, K., Thomas, P., Smits-Engelsman, B., & Steenbergen, B. (2016). Motor imagery training enhances motor skill in children with DCD: A replication study. *Research in Developmental Disabilities, 57*, 54–62. http://dx.doi.org/10.1016/j.ridd.2016.06.014.

Wilson, P. H., Smits-Engelsman, B., Caeyenberghs, K., Steenbergen, B., Sugden, D., Clark, J., ... Blank, R. (2017). Cognitive and neuroimaging findings in Developmental Coordination Disorder: New insights from a systematic review of recent research. *Developmental Medicine & Child Neurology, 59*(11), 1117–1129.

Wood, G., Miles, C. A., Coyles, G., Alizadehkhaiyat, O., Vine, S. J., Vickers, J. N., & Wilson, M. R. (2017). A randomized controlled trial of a group-based gaze training intervention for children with Developmental Coordination Disorder. *PUBLIC LIBRARY OF SCIENCE, 12*(2), e0171782. http://dx.doi.org/10.1371/journal.pone.0171782.

Yu, J., Sit, C. H., Burnett, A., Capio, C. M., Ha, A. S., & Huang, W. Y. (2016). Effects of fundamental movement skills training on children with developmental coordination disorder. *Adapted Physical Activity Quarterly, 33*(2), 134–155. http://dx.doi.org/10.1123/APAQ.2015-0008.

Zamani, M. H., Fatemi, R., & Soroushmoghadam, K. (2015). Comparing the effects of self-controlled and examiner-controlled feedback on learning in children with developmental coordination disorder. *Iranian Journal of Psychiatry and Behavioral Sciences, 9*(4), e2422. http://dx.doi.org/10.17795/ijpbs-2422.

Zwicker, J. G., Rehal, H., Sodhi, S., Karkling, M., Paul, A., Hilliard, M., & Jarus, T. (2015). Effectiveness of a summer camp intervention for children with developmental coordination disorder. *Physical and Occupational Therapy in Pediatrics, 35*(2), 163–177.