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Intervention for Children with Developmental Coordination Disorder: A Systematic Review

Susan Hillier, PhD
Senior Lecturer, School of Health Sciences
University of South Australia

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Abstract
Prevalence of children with developmental coordination disorder (DCD) is high (6-13% of all school children) and the negative impact of their movement difficulties on their participation in recreation and academic pursuits is well documented. This secondary research systematically reviewed the available literature for evidence of effectiveness of interventions that aim to improve the movement capability of children with DCD. Specified databases were searched for appropriate studies, these were retrieved and two reviewers appraised the level and quality of evidence. Thirty one studies were included between levels I and III-3 of the NH & MRC protocol. Scoring using an established critical appraisal tool demonstrated variable quality. Meta-analysis was not possible due to the clinical heterogeneity of the primary studies. A best evidence synthesis of results was conducted, producing clear evidence that no intervention has poor results when compared to any intervention. The high number of purportedly different interventions and variable quality make definitive conclusions about the merits of specific approaches difficult. There may be generic qualities or factors in the studied interventions that are more important for effectiveness than specific content. More information is needed on the underlying mechanisms of DCD, factors influencing effectiveness and the broader pragmatics of intervention delivery.

Introduction

Developmental coordination disorder (DCD) encompasses a complex presentation of sensory and motor impairments in children that can result in significant restrictions of daily activities and participation in life roles. The estimated prevalence (depending on severity criteria) is between 6 and 13% of all school aged children[1], with some reports finding that boys experience a higher incidence than girls[2] and that social disadvantage may also increase incidence[3].

Nomenclature for children experiencing motor difficulties in this group varies internationally although the current term – DCD – was accepted at the International Consensus on Children with DCD in 1994.[4] Other terms used (and possibly reflecting sub- or allied groups) include minimal motor dysfunction, deficits in attention, motor control and perception (DAMPS), minimal cerebral/brain dysfunction, developmental dyspraxia, motor (dys)praxia, "clumsy child" and perceptual motor dysfunction.[4] The current consensus for diagnosis of DCD is based on the DSM-IV (American Psychiatric Association) and includes: marked impairment of the development of motor coordination, significantly interfering with academic achievement of activities of daily living, not due to a general medical condition (e.g. Cerebral Palsy), criteria are not met for Pervasive Developmental Disorder and if mental retardation is present, the motor difficulties are in excess of those usually associated with it.[5]

Macnab, et al. (2001) identified five sub-types of children with DCD, characterised by varying proportions of impairment in gross and fine motor function, and/or sensory acuity. Other authors have reported varying characteristics such as information processing deficits (particularly visuo-spatial); reliance on visuo-spatial memory for learning movements; being perceived externally as having poor effort and reduced motivation, secondary effects of lower fitness levels or restricted social skills; and co-morbidity with learning delay (LD),

developmental language disorder (DLD) and attention deficit and hyperactivity disorder (AD/HD).[6-13]

Not surprisingly with such a heterogenous group, identification and diagnosis of children with DCD is difficult. Observations by the parent/s, and/or teacher/s may be reported and followed up with any number of professionals including paediatricians, occupational and physical therapists and psychologists. It is generally accepted that no one test is sufficient to identify all children; rather a problem solving approach, plus an exclusion of other disorders, is required.[14] Geuze, et al. (2001) reviewed the clinical and diagnostic literature and recommend scores on standardised motor tests below the 15 percentile, coupled with IQ scores over 69, as the diagnostic criteria, in compliance with the DSM-IV definitions. [14]

The underlying mechanisms for DCD are still under investigation. By definition there are no 'hard' neurological signs or pathology; in other words, no macroscopic anomalies. Abnormal microscopic function – at the neurotransmitter or receptor level within the central nervous system - is a matter for conjecture.[1] Earlier theories focused on sensory-integration deficits (the hierarchical or neurodevelopmental perspective), that postulated issues with integrating sensory information.[15] These early ideas arose from the view that DCD may be a minimalist form of Cerebral Palsy.[16] These were followed by more cognitive based theories suggesting difficulties with the problem solving aspect of motor control.[16] Current understandings are influenced by the inclusion of recent information from the motor learning literature and dynamic systems theories including the influence of task and environment on an individual's development.[17, 18] Neuronal group selection theory ties in with neuroplasticity research, which suggests that children may have impoverished repertoires of movement and sensing and that this can be exacerbated by reduced opportunities for experience and learning (also linked with social disadvantage)[1] .

Intervention approaches to assist children with DCD to establish more skilled action in home and school activities are based on the several theories. Barnhart, et al. (2003) and Wilson (2005) have provided summaries of the interventions currently in the literature, discussing the content and theoretical standpoint of the various paradigms.[16,19] International consensus meetings have agreed that intervention should be holistic, child-centered and individualized for the unique characteristics of the child.[4] Broader questions of when to intervene, at what age, in which environment and who should intervene have not been as well investigated as the specific approaches.

Research into the effectiveness of these varied interventions for DCD has produced extensive literature, with narrative reviews produced by several authors.[15,16, 20] Three meta-analyses have pooled data using an evidence based framework. The first by Kaplan, et al. in 1993, combined data from two studies both specifically investigating perceptual-motor versus sensory integration approaches versus no intervention, finding that both groups who received intervention improved similarly compared to little change with the no intervention group.[21] Miyahara (1996) produced a meta-analysis of four DCD intervention studies, concluding motor intervention per se is better than nothing but that there was no evidence for one approach over another.[22] The inclusion criteria for the identified studies were not systematic. The author also categorized the studies into task-oriented versus process oriented. The more recent meta-analysis that reported exclusively on children with DCD found 21 studies comparing three different approaches (general, sensory integration and specific skill) and included 13 of these in a meta analysis.[23] These authors concluded that some form of intervention is useful, particularly using the specific skill approach, targeting children five years and over, either in groups or at home, with a frequency of at least 3-5 times per week. This paper only included research until 1996 and, because of the selection process for meta analysis, only drew conclusions from a sample of the evidence. Therefore it was considered timely to revisit the literature and perform a systematic review of all investigations to date concerning interventions for children with DCD.

Systematic reviews involve *a priori* search methodologies to ensure all relevant literature are found (no search bias) and analyzed in a standardized and repeatable fashion (no reporting bias). The appraisal usually involves two stages to ascertain levels of bias (and therefore trustworthiness or validity) of individual clinical trials. Results can then be considered as a body of evidence, either combined narratively, in a discussion, or statistically (if studies are sufficiently similar and report the requisite data). Systematic reviews therefore offer consumers, service providers and researchers a single point of reference when considering the effectiveness of interventions for given conditions. Summary table/s offer individual readers the opportunity to make decisions based on their individual circumstances and to seek further information within individual trials as needed.

As such, the aims of this secondary research were to:

1. Systematically identify all intervention based research investigating the effectiveness of defined approaches with children with DCD.
2. Identify the levels and quality of evidence for effectiveness.
3. Formulate implications for management and future research

Methods

Criteria for review

Preferred studies for this review were identified from the published literature as systematic reviews (and/or meta-analyses) of randomised controlled trials (RCT's), RCT's, pseudo-randomised / controlled clinical trials (CCT), non-randomised clinical trials (NRCT) or comparative studies (levels I-III)[24].

Study participants were children of any age, identified with DCD (or allied terms) by recognized tests, and exclusion of children with other neurological diagnoses or significant intellectual disability.[14] Interventions could be of any type provided they were defined, and did not involve pharmacology or surgical intervention. Possible comparisons could include the intervention with a placebo, a control, another intervention or no intervention. Types of outcome assessment accepted included a change in motor performance as demonstrated by a recognized test (at minimum) evaluating impairment, activity or participation restriction.

Search Strategy

Databases searched included AMED, Australasian Medical Index, Austhealth, Cinahl, Cochrane Controlled Trials Register, Current Contents, Medline, PubMed, SPORT Discuss, PEDro, PsychInfo, Australian Public Affairs, Blackwell Synergy, AUSTROM, Academic Search Elite, ERIC, Health Source Consumer and Health Source Nursing/Academic. No limit was set for the date of publication. To reduce the likelihood of publication bias or missing published information (for instance articles not referenced in the selected databases), manual searching of the reference lists of all retrieved articles was also undertaken to identify additional relevant citations. Search terms were constructed after consultation with staff involved in the area of children's health and education from within the University of South Australia and included all known DCD-like nomenclature (see introduction), with children, fine/gross motor skills, motor development, motor control, rehabilitation, therapy, treatment and exercise. The full search strategy is available from the author.

Methods of the review

The initial search produced titles and abstracts of articles, which were then reviewed by two reviewers against the review criteria. All selected studies were then retrieved in full, as were any studies where ambiguity existed.

A data spreadsheet was formatted to record study identification, author, date, title, diagnostic group, participant demographics, intervention and comparison, measurement, results/outcomes, study design (level), methodological quality score and notes section. The two reviewers then independently reviewed each full article and assessed the level of evidence (Table 1). Levels of evidence reflect the degree to which bias has been considered in the study design, with a lower rating on the hierarchy indicating less bias.[24]

Table 1: NH&MRC Levels of evidence (1999)

Grade	Definition
I	Evidence obtained from a systematic review of all relevant randomized controlled trials.
II	Evidence obtained from at least one properly-designed randomized controlled trial.
III-1	Evidence obtained from well-designed pseudo-randomized controlled trials (alternate allocation or some other method).
III-2	Evidence obtained from comparative studies with concurrent controls and allocation not randomized (cohort studies), case-control analytic studies, or interrupted time series with a control group.
III-3	Evidence obtained from comparative studies with historical control, two or more single-arm studies, or interrupted time series without a parallel control group.
IV	Evidence obtained from case series, either post-test or pre-test and post-test.

For papers designated as clinical trials (CTs, levels II and III), methodological quality was also evaluated independently by the two reviewers. The PEDro scale (Physiotherapy Evidence Database) was chosen to evaluate all CTs because it is simple, efficient and widely used in allied health literature.[25] The PEDro scale is an 11-point scale with dichotomous (yes / no) responses that account for key quality aspects of an experimental study. Criterion 1 relates to the external validity of the trial, criteria 2-9 relate to the internal validity of the paper, while criteria 10-11 provide information about statistical analysis. For each fulfilled criterion, one mark is given, and the scores are summed to provide a total.

Data Synthesis

Due to the clinical heterogeneity of the retrieved studies in terms of intervention approach and outcome measures, meta-analysis was not appropriate and thus the results were reported as a best-evidence synthesis of findings. [26] Using this paradigm, all studies meeting the review criteria could then be considered. These were grouped in a table of included studies and the rejected into a second table of excluded studies. The result/s of each trial were

summarised as either a '+' for significant improvement in the experimental group/s, '0' for no change or '-' for a decrease in performance. The particular outcome measure for these results was noted after in parenthesis. Positive improvements were defined by a *p*-value <0.05. To allow consideration of the body of evidence, the criteria established by Van Tulder et al. (1999) (Table 2) were applied which are based on the methodological quality scores of the PEDro scale.[27] This enables groups of studies to be categorized into five grades of evidence ranging from strong to no or insufficient evidence.[26]

Table 2: Best evidence synthesis (adapted from van Tulder, et al., 1999)

Grade of evidence	Criteria
	Statistically significant findings in outcome measures in:
Strong evidence	at least 2 high quality RCTS (PEDro scores of at least 4 points)*
Moderate evidence	at least 1 high quality RCT **and** at least one low quality RCT (≤ 3 PEDro score) **or** 1 high quality CCT*
Limited evidence	at least 1 high quality RCT **or** at least 2 high-quality CCTs* (in the absence of RCTs)
Indicative evidence	1 high quality CCT **or** low quality RCTs* **or** 2 studies of a non-experimental nature with sufficient quality
No / insufficient evidence	In the case that results of eligible studies do not meet the criteria for above grades **or** in the case of conflicting (statistically significant positive and negative) results among RCTs and CCTs **or** in the case of no eligible studies.

** if the number of studies with positive findings is < 50% of the total number of studies found within the same category, then the grade "no evidence" will be applied.*
RCT: randomized controlled trial; CCT: controlled clinical trial.

Each approach was reported as named in the original primary research. It was beyond the scope of a systematic review to provide an analysis of the underpinnings of each approach. This would need to be consensus driven - currently there is no agreed framework on which to base such analysis.

Results

Eighty seven studies were identified as meeting the criteria for inclusion. Of these, 40 studies were excluded as they did not meet the criteria of only children with DCD or did not include an intervention (copies of the excluded studies table with reasons for exclusion can be obtained from the author). The dates of publication ranged from 1970 to 2004.

Level and quality of evidence

Forty seven studies were included in the final appraisal process and were allocated to the levels of evidence as summarised in Table 3.[24] Level IV studies were identified but will not be reported in this article.

Table 3: Number of papers sourced according to level of evidence

Level of evidence	I	II	III-1	III-2	III-3	IV	Total
Number of papers	1	16	4	7	3	16	47

Of the 31 studies identified as level I to III-3, 28 were primary studies and scored for quality, with their PEDro criteria scores summarised in the Table of included studies (Table 4). Two papers were scored as level II but could not be scored on PEDro as they reported non-systematic reviews of RCTs. The sole level I paper was also not scored. Overall the quality was highly variable with a mean of 5.57, range 3-9, (maximum score out of 11). Only two papers (Polatajko, et al. 1995; Leemrijse, et al. 2000) reached 9/11 which is considered a high score for clinical trials.[28,29]

Table 4: Table of included studies (by level). Quality scores (QS / 11) are indicated in the left column under the NH&MRC level and full explanations of abbreviations follow the table.

Level (QS/11)	Author, date	Cohort (N)	Outcome Assessment	Intervention	Results
I	Pless & Carlsson, 2000[23].	DCD	Various in studies	General vs SI vs Specific skill	21 papers: 13 for meta analysis. Supports: specific skill interventions, at >5 yrs old, delivered in groups or at home, 3-5x per week intensity.
II (6)	Humphries, et al., 1990[30].	SI dysfn/LD (30)	BOTMP, PRN, SC-SIT, VMI, Ayres, WISC-R etc for academic skills	SIT vs PMT vs nil	SIT +, PMT 0, nil 0 (motor tests); SIT, PMT, nil all 0 (academic tests)
II (7)	Humphries, et al., 1992[31]	SI dysfn/LD (103)	SC-SIT, PRN, BOTMP,VMI, academic tests	SI vs PM vs nil	PM +, SI 0 (design copying, BOTMP); SI +, PM/nil 0 (motor planning); SI, PM, nil all 0 (academic tests)
II (7)	Humphries, et al. 1993[32]	SI dysfn/LD (103) as for 1992	SC-SIT, PRN (no. of dysfunctions and severity)	SI vs PM vs nil	PM +, SI +, nil 0 (no. and severity of dysfn)
II (4)	Jarus & Gol, 1995[33]	SI problems (27)	Throwing target test	UE vs LE WB (kinesthetic) (+matched norms)	WB + (motor tests), UE > LE Ex
II (*)	Kaplan, et al., 1993[21]	DCD/SI dysfn	Various academic tests BOTMP	SIT vs PMT vs nil/tutoring	2 papers All groups receiving intervention improved, no one more than another.
II (5)	Laszlo & Sainsbury, 1993[34]	PMD (low kinesthetic scores) (42)	PMAT, TOMI (not well reported)	KT vs KT/S/T vs Writing/high motor content	KT +, KT/S/T + (PMAT)
II (6)	Miller, et al., 2001[35]	DCD (20)	COPM, PQRS, VABS, BOTMP, VMI, SPPC	CO-OP vs CTA	CO-OP + > CTA (COPM, PQRS, VABS) CO-OP = CTA (BOTMP) Gains maintained at follow-up (COPM not blind tested, some pre differences btn groups)
II (*)	Miyahara, 1996[22]	DCD (meta-analysis)	Various in studies (M-ABC, TOMI etc)	Task-oriented vs process oriented	4 papers: motor intervention per se is better than no Rx, but no differences btn types
II (4)	Platzer, 1976[36]	LD (motor issues) (36)	Cratty gross motor; Goodenoughs.	PMT vs nil	PMT + , nil 0 (Goodenough tests)
II (6)	Polatajko, et al., 1991[37]	SI dysfn/LD (67)	WJPEB, BOTMP, BASE, PIC	SI vs PM	SI + = PM + (academic and motor tests)
II (9)	Polatajko, et al., 1995[28]	DCD (76)	SC-SIT, KST, VMI, TOMI	PO vs traditional (sensory-motor) vs nil	Mixed results PO = traditional PO + (KST) ? very severe group need repetition
II (6)	Valentini & Rudisill, 2004[38]	DD (motor) (#1 n= 39) (#2 n=56)	PSPCSA, TGMD, parent qu (#2 only) (no PSPCSA for control gp)	#1: Motor skill + mastery vs motor skill w/o #2: motor skill + mastery vs nil (freeplay)	#1 Mastery +, w/o 0 (PSPCSA, TGMD) #2 Mastery +, nil 0 (TGMD). Also maintained gains at 6 months, nil decreased in some aspects.
II (4)	Watter & Bullock, 1983[39]	MCD and LD (62)	SM Ax, various academic tests	PT vs nil	PT + , nil 0 (academic tests)
II (6)	Watter & Bullock, 1987[40]	MCD (64)	Physio ND Ax	Indiv PT & home Ex vs nil	PT + , nil 0 (ND Ax) Maintained gains at 6 months
II (7)	Wilson, et al., 1992[41]	Motor incoord + SI dysfn (29)	VMI, BOTMP, SCSIT, PCPCSA, clin obs, PRN, behavioral, psycho-educational, handwriting	SIT vs individual tutoring	SIT +, Indiv + (motor and academic tests)
II (5)	Wilson, et al., 2002[42]	DCD (54)	M-ABC	MI vs PM vs nil	PM = MI +, nil 0
III-1 (6)	Hamilton, et al., 1999[3]	Risk of DD (motor) (27)	TGMD	Parent assisted motor skill intervention (object control) vs nil	Intervention +, nil 0 (TGMD)
III-1 (5)	Pless, et al., 2000[43]	DCD (37)	M-ABC	Group motor skills vs nil	Intervention = nil ? borderline subgroup did gain with intervention
III-1 (6)	Sims, et al., 1996a[44]	DCD/clumsy (20)	TOMI, KST, PEST, shape copying, handwriting	KT vs nil (then cross over)	Both groups + (all tests) ? PEST produced change in itself
III-1	Sims, et al.,	Clumsy	TOMI, shape copying,	KT vs CA vs nil	KT & CA + nil 0 (TOMI)

(6)	1996b[45]	(36)	handwriting, teacher checklist		? effect more from presentation than content
III-2 (6)	Allen, 1971[46]	Motor impaired (12)	Stott	Effort training (movement quality) vs usual sport	Effort +, sport alone 0
III-2 (5)	Davies & Gavin, 1994[47]	DD (motor) (18)	PDMS, VABS, CIDPPS (for academic)	Indiv OT/PT vs group/consultative	Indiv = group + (motor tests)
III-2 (4)	Laszlo, et al., 1988[48]	PMD (40)	PMAT, TOMI	KT/S/T vs KT vs spatial only vs fine/gross work	KT/S/T & KT +, others 0 (PMAT, TOMI)
III-2 (3)	Marchiori, et al., 1987[49]	Physically awkward (2)	Specific task (hockey slap) – kinematic analysis	Task specific reps (1200x)	Timing and velocity of task remained variable in subjects compared to controls.
III-2 (4)	Revie & Larkin, 1993[50]	Incoord (24)	Task specific tests (throw, hop, catch, kick)	Task spec (kick, bounce) vs task spec (throw, hop)	Task Spec (kick bounce) + (kick bounce tests); Task Spec (throw hop) + (throw tests)
III-2 (5)	Rintala, et al., 1998[12]	Subgroup of DLD with DCD (54)	M-ABC TGMD	P-M training Vs RPE classes	P-M = RPE + (M-ABC, TGMD) P-M group +, RPE 0 (object control test, M-ABC)
III-2 (3)	Schoemaker, et al., 2003[51]	DCD (15)	M-ABC CAMCH	NTT Vs nil	NTT +, nil 0 (all tests)
III-3 (5)	Kernahan, et al., 1986[52]	PMD (82)	Motor Battery (Arnheim & Sinclair, 1979), B-P reflex test	PM (school based, individualized) vs nil	PM +, nil 0 (most gross motor areas) (repeated in crossover design)
III-3 (9)	Leemrijse, et al., 2000[29]	DCD (6)	M-ABC, Praxis test, Rhythm test, VAS for parents	LBD vs SIT (crossover)	LBD = SIT + (all tests) after combin of Rxs; LBD>SIT on some.
III-3 (7)	Sugden & Chambers, 2003[53]	DCD (31)	M-ABC	Guided teacher / parent intervention	Intervention + (M-ABC) In 27out of 31 children

Explanatory notes and Abbreviations (by column and alphabet):
Level:
Levels I-IV (refer Table 2 for definitions)
QS/11 – quality score out of 11 total for PEDro Scale
(*) - meta-analyses of other papers (also appearing in table), non-systematically derived. Unable to score for quality.

Cohort:
DCD – developmental coordination disorder
DD – developmental delay
DLD – developmental language disorder
Incoord – incoordination
LD – learning difficulties
MCD – minimal cerebral dysfunction
N – number
PMD (low kinesthetic scores) – perceptual-motor dysfunction (subgroup)
SI dysfn – sensory integration dysfunction/problems
#1, #2 – study 1, study 2

Outcome assessment, with frequency of use in parenthesis:
Academic tests – not specified (4)
Ayres – presumably versions of SC-SIT etc (1)
Ax – assessment
BASE – Behavioral academic self-esteem rating scale (1)
Beery test – see VMI
BOTMP – Bruininks-Oseretsky test of motor proficiency (5)
B-P reflex test – Bender Purdue reflex test (1)
CAMCH – Concise assessment measure for children's handwriting (1)
CIDPPS – Central Institute for deaf pre-school performance scale (Quasi academic test for intelligence quotient) (1)
Clin Obs – clinical observations (1)
COPM – Canadian occupational performance measure (1)
Cratty – Cratty six category gross motor tests (1)
DTVMI – see VMI
Goodenough – Goodenoughs house etc (perceptual tests) (1)
Handwriting – not specified (3)
KST – Kinesthetic sensitivity test (2)
M-ABC – Movement assessment battery for children (6)
Motor battery – not specified (1)
ND Ax – Neuro-developmental assessment (physiotherapy based) (1)
Parent qu – parent questionnaire (1)
PDMS – Peabody developmental motor scales (fine and gross motor) (1)

PEST – Parameter estimation by sequential testing (1)
PIC – Personality inventory for children (1)
PMAT – Perceptual-motor abilities test (2)
PQRS – Performance quality rating scale (1)
Praxis test – not specified (1)
PRN – Post-rotatory nystagmus test (4)
PSPCSA – Pictorial scale of perceived competence and social acceptance (2)
Rhythm test (not specified) (1)
SC-SIT – Southern Californian sensory integration tests (5)
Shape copying – not specified (2)
Specific task – tests for specific task e.g. hockey slap, hop, throw, catch, kick etc (2)
SM Ax – Sensory motor assessment (1)
Stott – test for motor impairment (Precursor of TOMI) (1)
SPPC – Self perception profile for children (1)
Teacher qu – teacher questionnaire (1)
TGMD – Test of gross motor development (3)
Throwing target test – not specified (1)
TOMI – Test of motor impairment (precursor of M-ABC) (5)
VABS – Vineland adaptive behavior scales (2)
VAS – visual analogue scale (parents) (1)
VMI – (Developmental test of) Visual motor integration, also known as the Beery-Buktenica DTVMI (5)
WISC-R – Wechsler intelligence scale for children – revised (1)
WJPEB – Woodcock-Johnson psycho-educational battery (1)

Interventions, with frequency of investigation in parenthesis:
CA - Cognitive affective – tasks (draw, mime, visual) with emphasis on experiencing success and self monitoring (1)
CO-OP – Cognitive orientation to daily occupational performance (1)
CTA – Contemporary treatment approach (1)
Effort training – based on training the specific movement qualities proposed by Laban (1)
Ex – exercises – see more specific forms
Fine/gross work – not specified (1)
Gp – group program (2)
Guided teacher/parent – intervention prescribed by therapists for teachers/parents to conduct (1)
Home Ex – home exercises prescribed by PT (1)
Indiv PT/OT – individual physio and occupational therapy
Indiv tutoring – provided 1:1 teaching (1)
KT - Kinesthetic training – process oriented approach proposed by Laszlo (4)
KT/S/T – kinesthetic training with spatial and temporal programming (2)
LE – lower extremity (see WB)
LBD - Le Bon Départ – psychomotor therapy, includes emphasis on music and rhythm (1)
Mastery – training paradigm that complies with requirements for high autonomy level versus low autonomy/mastery (2)
MI – Motor imagery – training in visual, predictive timing, relaxation, mental preparation, modeling, mental rehearsal etc (1)
NTT – Neuromotor task training – task oriented, based on recent motor learning/control research (1)
Parent assisted – home Ex prescribed by therapist and conducted by parents (1)
PE – physical education; (RPE – regular physical education) (1)
PMT or PM – perceptual-motor (therapy) "doing"; based on Bobath etc (9)
Psychomotor training – gross motor, ball skills and body awareness. (1)
PO - Process oriented – based on kinesthetic training proposed by Laszlo (1)
PT – physical therapy or physiotherapy (2)
SIT or SI – Sensory integration (therapy); based on Ayres (7)
Spatial training – based on Laszlo (1)
Task Spec reps – repetitive training or practice that is specific to a task (2)
Traditional – sensory-motor – not specified (1)
UE – upper extremity (see WB)
Usual sport – participation in usual school based sporting activities (1)
WB – weight bearing (kinesthetic training) (1)
Writing – high motor content (1)

Results:
(see outcome assessment and interventions lists for most abbreviations)
+ - positive effect
0 - no effect/equivocal effect
= - one intervention had same effect as other (either + or 0).

Cohort

A total of 1105 children with DCD (or like terms) participated in the combined studies.

Outcome Measures

Within the 28 primary studies (all levels), over 42 different outcome measures were used for pre and post intervention testing. This does not include the tests used for identification or subsidiary aims. The overall frequency of usage is noted in parenthesis after each outcome assessment definition following Table 4. The most frequently used assessment was the Movement Assessment Battery for Children (M-ABC) used 6 times, followed by the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP), the Developmental Test of Visual Motor Integration (VMI), the Southern Californian Sensory Integration Test (SC-SIT), and Test of Motor Impairment (TOMI - a precursor of the M-ABC) all used 5 times. These are all general tests for motor function. Outcome measures reported less frequently were often specific for the task, sensory process, or behaviour underlying the intervention itself or in other instances were miscellaneous tests for academic performance, self-perception and awareness.

Interventions

Numerous interventions were reported – over 30 differently titled approaches. We chose to use the self-ascribed nomenclature for the approaches. Assuming that those who used the same nomenclature were actually using the same approach, the most commonly investigated approaches were perceptual-motor therapy (PMT) and sensory-integration therapy (SIT) (9 and 7 respectively), followed by kinesthetic training (4).

Considering the results descriptively, 15 studies included a "nil" intervention group. Of these, no studies reported that nil intervention had a positive result (as recorded by the identified outcome measures), 2 measures demonstrated "nil" had an equivocal result (or at least equal to the intervention) and 14 measures indicated that nil intervention produced significantly lesser results than the intervention/s. Using best evidence synthesis, there is *strong evidence* that intervention is better than no intervention for children with DCD.

Of the 9 studies investigating PMT, 8 measures demonstrated that PMT had a positive (superior) effect, and for 4 other measures it was inferior to the comparison intervention (there are more measured effects than studies because some studies used more than one outcome measure). With the 7 SIT studies, 6 measures reported a positive effect, with 4 demonstrating inferior effects. There is therefore *strong evidence* that these approaches are effective for children with DCD. However these two interventions also had reports of lesser or nil effects that accounted for between 33 and 40% of outcomes, which obviously approaches the cut off defined in best-evidence synthesis (50%) (see table 2).

Physiotherapy and the incorporation of mastery concepts were both investigated twice and in both studies showed positive effects compared to alternative interventions. There is *strong evidence* to support these approaches as all studies were high quality RCTs.

The kinaesthetic training studies (4) all reported positive effects with their outcome measures, and no equivocal or negative effects. However only one of these was an RCT and so there is *moderate evidence* that this approach is effective.

The following level II (RCT) studies were all investigated once and showed positive effect/s: weight bearing exercises, writing, cognitive orientation to daily occupational performance (COOP), contemporary treatment approach (CTA), process oriented, traditional, individual tutoring and motor imagery. These therefore offer *limited evidence* for effectiveness.

Parent-assisted motor skills, movement quality (effort) training, individual and group programs, psychomotor, neuromotor task training (NTT), Le Bon Départ (LBD) and guided parent or teacher intervention were also investigated once with positive outcomes, but were CCT's or less and therefore only offer *indicative findings*. For the task specific studies (3) one measure demonstrated positive effects and 2 were equivocal. None of these were RCTs, therefore there is only *indicative findings* of the effectiveness of this approach.

Discussion

From this systematic review, there is sufficient evidence, of sufficient quality, to strongly confirm that intervention per se is better than nothing for children with DCD.

There is also strong evidence for several approaches. The most widely investigated (PMT and SIT) more often than not, produce a positive effect, however there is a cautionary rider in the interpretation of this given the level of negative or nil effects also reported. Physiotherapy and mastery concepts also have been reported in sufficient quantity and quality to support their grade of strong evidence. The body of evidence for all other approaches was less strong (in quantity and/or quality) and therefore more difficult to interpret. It also must be acknowledged that a clear delineation of what is really occurring within individual approaches is lacking, that is to say what is it within these approaches that is effective or not.

There is a trend in other clinical areas (for example stroke rehabilitation, psychotherapy and cognitive behavioral therapy) to interpret such findings as supportive of generic effective attributes within any (or all) interventions. In the area of DCD, such an idea seems feasible, with other authors noting the possibility of meta-themes such as positive feedback, high autonomy engendering feelings of

mastery and self-competence, involvement of parents and teachers, education of all people involved in the care of the child and tailoring of interventions to the individual child. We noted a paucity of studies looking at the pragmatics of intervention delivery such as *where* (e.g. in the school, home or clinic environment), and *by whom* (teachers, parents, various clinicians, support officers). There is also limited research into other modes of intervention such as enhanced education and awareness, ecological change or enrichment of current environments.

There is much conjecture about the underlying physiology of the DCD phenomena and therefore much dissension about the underlying philosophies of intervention approaches. The literature is well endowed with strong opinions and each approach is presented as unique and specific. However there appears to be significant overlap, making it difficult for the reader to be convinced of clear distinctions. We took each approach as self described as it was considered beyond the scope of the systematic review to attempt to de-construct the individual underlying philosophies and components and from there to combine approaches. The useful evaluative review by Wilson (2005) provides one framework to group the various approaches and outcome measures based on their underlying theoretical assumptions. Further research into causation will clarify these issues.[19]

When considering the individual approaches with the outcome measures used (Table 4) there is evidence to support the idea that what is trained is what is improved, whether that be sensory based or motor skill based. For example if kinesthetic skills are trained then improvements with kinesthetic tests are demonstrated; if a cognitive or goal oriented approach is taken then goal behaviors will improve. This supports current thinking in neuroscience relating to task specificity. Researchers and clinicians need to carefully consider the plethora of outcome measures, some of which are custom-designed to measure the specific intervention. Clearly outcome measurement needs several elements: assessing the specifics of the intervention but also to assess at broader, participation levels that are more meaningful for the child and their environment. This latter feature would allow more meaningful comparison of individual approaches.

The broader DCD literature confirms there is a significant problem facing education, health and welfare agencies concerned with the activity and participation levels of children experiencing delays in their fine and gross motor skills[9]. These children are not only at risk of lower levels of participation in social and recreational pursuits but are also experiencing lower achievement levels in academic activities, and are seen to have lower feelings of self-competence and esteem. These children do not necessarily "catch-up" as they become older.[54-56] There is therefore a strong mandate for intervention/s to be offered. High quality research and investigation into these children is essential, particularly to identify the factors that improve or influence intervention effectiveness.

Conclusion

Intervention for children with DCD is strongly supported by a rapidly growing body of literature. Given the consistent positive results across clinically heterogeneous studies, it may be that generic attributes account for the effectiveness more than specific content. Further research is needed into the mechanism/s underlying DCD to inform intervention. Also further investigation is required into the effective factors of intervention as well as the pragmatics of service delivery to inform current providers. Future research needs to be well designed and multidisciplinary, using a mixture of precise outcome measures as well as general indicators of participation levels in meaningful contexts for these children.

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