Standardized motor assessments before the age of five predicting school-aged motor outcome including DCD: A systematic review

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A R T I C L E   I N F O

A B S T R A C T

Aim: Developmental Coordination Disorder (DCD) is a common neurodevelopmental disorder usually diagnosed at primary-school-age. This systematic review aimed to summarize available standardized motor assessments before five years of age predicting DCD, complex Minor Neurological Disorder (cMND) and motor delay assessed by a standardized motor test.
Methods: A systematic search was performed in MEDLINE, CINAHL, WoS, Scopus, CENTRAL and ERIC. A hand search was executed. Only data of non-Cerebral Palsy children was included.
Results: At or before two years, the BSID, motor subtests of GMDS, NOMAS, and NSMDA might be valuable in detecting school-aged motor delay, while starting at three years, the PDMS, motor subtests of GMDS, NSDMA, M-ABC-2, and CAMPB show promising results. General movements Assessment is associated with cMND, but does not seem sensitive enough to detect DCD. Predictive values are superior in high-risk groups and improve as children age. However, no assessment instrument reached 80% sensitivity and specificity.
Conclusion: Standardized motor assessments before five years seem valuable in detecting early motor problems. More longitudinal research commencing in infancy, including multiple assessments over time and the implementation of clear diagnostic criteria is imperative.

Contents

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Nomenclature

AIMS	Albert Infant Motor Scale
ASQ	Ages and Stages Questionnaire
Beery-VMI	Beery Developmental test of Visual-Motor Integration
BOT-(2)-(MP)(SF)	Bruininks-Oseretsky Test - (Second Edition) - (of Motor Proficiency) (Short Form)
BSID-I—II—III	Bayley Scales of Infant Development — First, second or third edition
CAMPB	Combined Assessment of Motor Performance and Behavior
(c)MND	(complex) Minor Neurological Dysfunction
CP	Cerebral Palsy
D	Day(s)
DCD-(Q)	Developmental Coordination Disorder - (Questionnaire)
DSM-V	Diagnostic and Statistical Manual fifth edition
EACD	European Academy of Childhood Disability
GmA-HA/P	General movements Assessment — by technique of Hadders-Algra/Prechtl
GMDS	Griffiths Mental Development Scales
M	Month(s)
M-ABC(-NL)	Movement Assessment Battery for Children - (Dutch Version)
MAND	McCarron Assessment of Neuromuscular Development
MOS	Motor Optimality Score
MPU	Motor-Perceptual Development
MSCA	McCarthy Scales of Children's Abilities
NBAS	Neonatal Behavior Assessment Scale
NOMAS	Neonatal Oral Motor Assessment Scale
NSMDA	Neuro-Sensory Motor Developmental Assessment
PDI	Psychomotor Developmental Index
PMA	Post-menstrual age
PDMS	Peabody Developmental Motor Scales
VABS-C)	Vineland Adaptive Behavior Scale - (Chinese version)
(V/E)(L)BW	(Very/Extremely) (Low) Birth weight
W	Week(s)
Y	Year(s)

1. Introduction

The Diagnostic and Statistical Manual fifth edition (DSM-V) defines Developmental Coordination Disorder (DCD) as early-onset (criterion C) deficits in acquiring and executing motor coordination skills (criterion A) [1]. These deficits significantly interfere with the performance of activities of daily living and impact on academic productivity, leisure, and play (criterion B). Difficulties cannot be attributed to other conditions, such as intellectual disability, visual impairment, or other neurological disorders that affect movement (criterion D). As advised by the European Academy of Childhood Disability (EACD), the diagnosis of DCD preferably occurs at primary-school-age [2]. Nevertheless, a growing body of literature recognizes the importance of early detection [3,4] as DCD may have a vast impact on the quality of life [5] and is associated with important secondary problems. The lower motor competence of these children has been associated with less vigorous physical activity, higher body fatness, lower physical fitness, and lower health-related quality of life [6—8]. Additionally, higher levels of motor impairment have been associated with less friendships and lower peer acceptance [9]. Unsurprisingly, the socio-emotional impact is high as these children often develop low self-esteem and experience significantly more emotional and behavioral problems [7,10]. Furthermore, children with DCD participate less in home, school, and community settings [11]. Having a diagnosis of DCD greatly

impacts the emotional, social, and financial well-being of the entire family [12]. Nevertheless, DCD and related terms such as dyspraxia are among the least known childhood disorders and too often remain unrecognized [13]. Many children with autism spectrum disorders, attention deficit hyperactivity disorder, and learning disorders likewise experience motor problems, sometimes resulting in a co-morbid diagnosis of DCD. Yet, motor problems are frequently considered a feature of another disorder or are simply overlooked. Minor Neurological Disorder (MND) is a condition detected by a standardized neurological examination which is strongly related to DCD [14,15]. The criteria for MND are age-specific and based on the number of dysfunctional neurological domains such as posture and tone, coordination and fine manipulative ability. While the first type 'simple MND' has limited clinical relevance and indicates that children have a typical but non-optimal brain function presenting a deviation in only a limited number of domains, the second type 'complex MND' (cMND) is clinically relevant as it is seen in children with non-optimal brain functions in several domains. Approximately 59% of children with probable DCD also adhere to the criteria for cMND [16]. Early detection and referral of DCD may considerably improve the health, socio-emotional, and educational outcomes of children with DCD [17,18]. However, accurate early detection is challenging because of the heterogeneous character of DCD and the great variability in early child development. A standard pediatric assessment is often

not sensitive enough to detect motor difficulties, therefore a standardized motor assessment is recommended when evaluating motor development in young children [19].

Several systematic reviews described the psychometric properties and predictive values of a great variety of early motor assessments. However, all reviews included a heterogeneous group of children with mixed mild and more severe neurological disorders such as Cerebral Palsy (CP) [20—22]. Additionally, most reviews focused only on very young children (<2 years). To the best of our knowledge, no review has focused primarily on the predictive values of early motor assessments regarding DCD, cMND, and significant motor delay on a standardized test at school-age. Therefore, this review aims to answer the following research question: Which standardized motor assessments before the age of five are available to accurately predict DCD, cMND, and significant motor delay on a standardized assessment in children aged five to twelve years(y)?

2. Methods

This review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement [23]. The review protocol has been registered and can be accessed on PROSPERO (https://www.crd.york.ac.uk/prospero/; registration number: CRD42018105599).

2.1. Search strategy

Exhaustive search strategies were developed and conducted by the first author of this article (ADR). Seven databases (MEDLINE (PubMed), Embase (Embase.com), CINAHL (EBSCOhost), Web of Science, Scopus, CENTRAL, and ERIC) were searched on 06/08/2018 and updated on 11/06/2020. The full search strategies can be consulted on PROSPERO.

2.2. Study selection

Studies were screened by two authors independently and were included if the following criteria were met: (1) observational study-design with follow-up period >1 year; (2) two standardized motor assessments, one performed before mean age of 5y and one between the mean age of 5y and 12y; (3) written in English, Dutch or French; (4) peer-reviewed published full-text articles. The chosen age-categories reflect the EACD-guidelines [24] advising to diagnose children with DCD preferably after 5y. The maximum age was set at 12y, excluding adolescents and adults whose diagnostic processes may be different. Studies were excluded for the following reasons: (1) interventional studies; (2) total sample size <20; (3) no report of a separate motor score; (4) studies focusing on neurological or cognitive assessments were excluded, unless a specific motor subtest was reported. When studies comprised children with CP, studies were only withheld when it was possible to deduct motor scores of non-CP-children or when authors provided the specific data on request. If not published, authors were asked to provide additional information on cross-tabs values. Multiple articles of the same study were included if different motor outcomes were presented in each publication.

2.3. Data extraction

Data extraction was performed independently by the first author using the following headings: author(s), number of participants, participant characteristics, name assessment, mean age at assessment, applied cut-off scores and the predictive values (specificity, sensitivity, positive predictive value (PPV), negative

predictive value (NPV), Area Under the Curve (AUC), correlation and regression coefficients, r^2, Odds Ratio (OR) and Likelihood Ratio (LR)) with significance levels. The authors of eight articles supplied additional data. Contingency tables (2 × 2) were extracted or constructed with the provided dichotomized data (presence/absence of a motor problem at baseline versus presence/absence of a motor problem at outcome assessment). To enhance comparison between studies applying General movements Assessment (GmA), only data reporting the quality of general movements or items of the Motor Optimality Score (MOS) are discussed in this review. Hence, analysis of specific GmA characteristics on item-level (e.g. presence of a specific movement pattern), the quantity of general movements, combinations of different items, or any other criteria related to general movements were not discussed.

2.4. Data synthesis and analysis

The myriad of outcome measures made it difficult to group results and prohibited a meta-analysis. Therefore, the results are discussed through a narrative summary per assessment instrument and outcome category. To enhance comparison, the following missing predictive values were calculated using MedCalc: sensitivity, specificity, PPV, NPV, relative risk (RR) and associated 95% Confidence Intervals (CI). Sensitivity refers to the percentage of children with a motor problem at school-age who also had a poor motor score before 5y of age. Specificity refers to the percentage of children without a motor problem at school-age who also had a good motor score before the age of 5y. Positive predictive value is the probability that the child will have motor problems at school-age if they have a poor motor score before 5y of age. Negative predictive value is the probability that the child will have a good motor performance at school-age if they have a good motor score before the age of 5y. If not reported and the necessary data was available, Chi^2 or Fisher-exact tests were conducted to determine the probability that the two points of measurement were coincidently related.
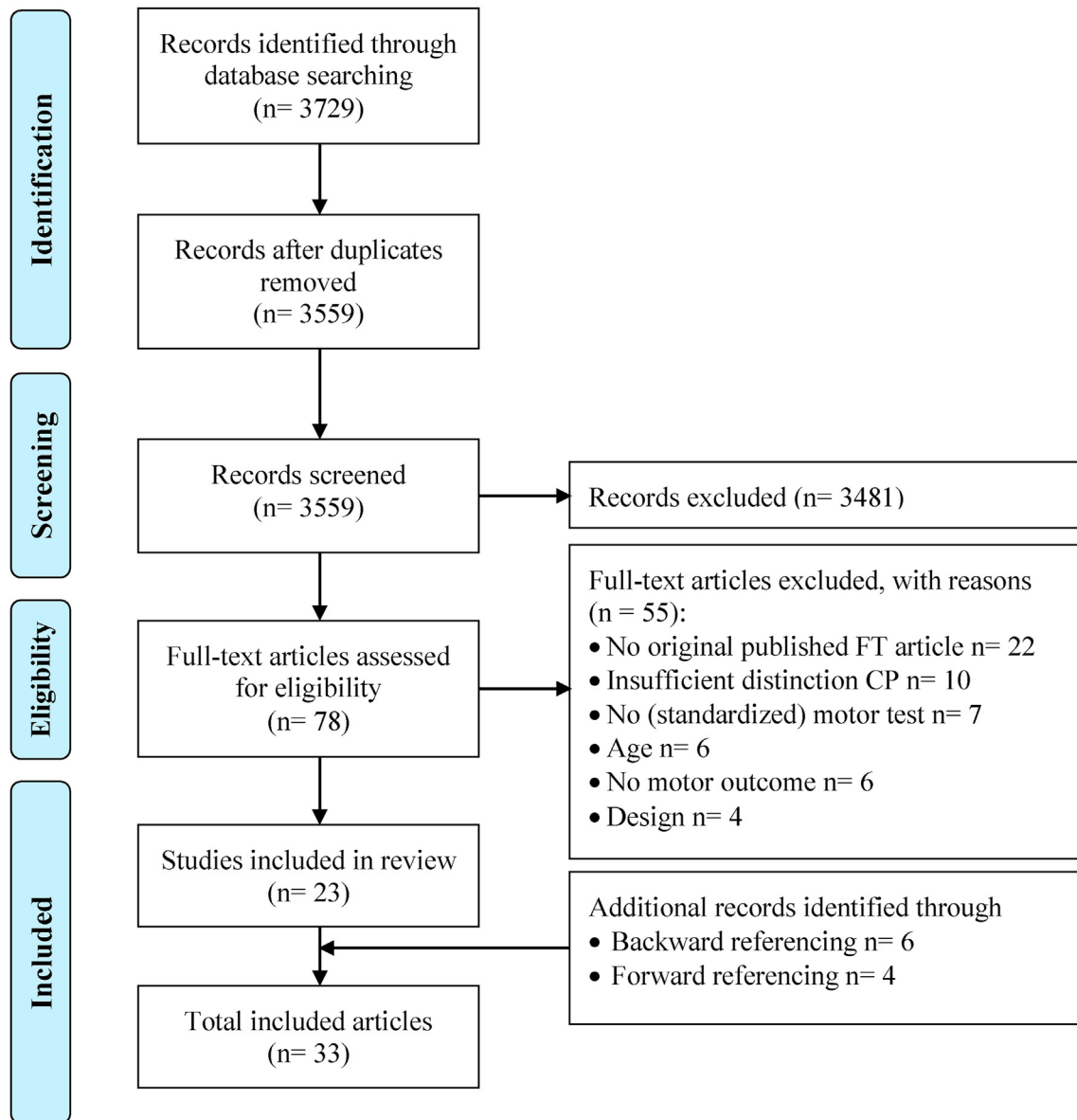
2.5. Methodological quality assessment

The methodological quality of each article was assessed by two authors independently using the Quality Assessment Tool for observational cohort and cross-sectional studies [25]. Study quality was rated as good (score ≥10), fair (7—9), or poor (≤6) based on 14 items.

3. Results

The database search resulted in 3729 articles whereof 3559 articles were withheld after deduplication. Two authors (ADR and HVW) independently performed the first screening, resulting in a remainder of 78 articles. Disagreements were resolved by consensus. After the second screening 23 articles were withheld. Almost perfect overall agreement was established at 92% (Cohen's kappa κ = 0.8). A hand search was completed, applying both backward (n = 6) and forward reference tracking (n = 4) on the included articles. This resulted in a total number of 33 included articles regarding 31 distinct studies. A detailed flow-chart of the selection process can be found in Fig. 1.

3.1. Study characteristics

The participant and study characteristics of the included studies are summarized in Table 1. Substantial clinical and methodological heterogeneity was present. The majority of studies were published after 2000. Most studies comprised high-risk children born either

Records identified through database searching (n= 3729)

Records after duplicates removed (n= 3559)

Records screened (n= 3559)

Records excluded (n= 3481)

Full-text articles assessed for eligibility (n= 78)

Full-text articles excluded, with reasons (n = 55):
- No original published FT article n= 22
- Insufficient distinction CP n= 10
- No (standardized) motor test n= 7
- Age n= 6
- No motor outcome n= 6
- Design n= 4

Studies included in review (n= 23)

Additional records identified through
- Backward referencing n= 6
- Forward referencing n= 4

Total included articles (n= 33)

Identification | Screening | Eligibility | Included

CP= Cerebral Palsy; N= number; FT= full-text.

Fig. 1. PRISMA flow diagram summarising the search process.

preterm (n = 15) or with severe neonatal complications or congenital anomalies (n = 3), whereas six studies comprised term low-risk children and another seven studies covered mixed groups of high- and low-risk infants.

A total of fourteen distinctive instruments were applied before 5y: GmA[26−39], Bayley Scales of Infant Development (BSID) [36,40−48], MOS, Peabody Developmental Motor Scales (PDMS) [49−51], Alberta Infant Motor Scale (AIMS) [47,48], Motor subtests of the Griffiths Mental Development Scales (GMDS) [50,52], Ages and Stages Questionnaire (ASQ) [53,54], Movement Assessment Battery for Children (M-ABC) [55], Neurological, Sensory, Motor, Developmental Assessment (NSMDA) [56], Motor scale of the Neonatal Behavioral Assessment Scale (NBAS), Combined Assessment of Motor Performance and Behavior (CAMPB) [57], Neonatal Oral-Motor Assessment Scale (NOMAS) [58] and NEPSY Copy Design Task [54]. Seventeen studies reported motor assessments before 6 months (m) [26−35,37−40,43,44,48,53,58], fifteen between 6m and 2y [36,40−44,46−53,56] and eight between 2 and 5y [45,49,50,53−57]. Within the baseline assessment age of this review (before 5y), eight studies evaluated children twice

[26,30,32,33,36,38,41,50,52], seven studies evaluated children three times [27,28,30,40,42,46,47,56], and six studies evaluated children four times or more [36,43,44,48,51,58]. Outcome measures were defined as (probable) DCD in four studies, cMND in five studies and significant motor delay on a standardized assessment in 23 studies. Follow-up length varied greatly between two and eleven years.

Predictive values (Sensitivity, specificity, PPV, NPV, or RR) were available in seventeen studies. Correlation coefficients were available in nine studies while another fifteen studies accounted for confounding variables applying various statistical models. No expedient data could be extracted out of three articles [34,49,51] leaving 30 articles with fitting data.

Study quality was rated as good in 20 articles [27,28,30,32−34,36−38,40,42,45−49,52,55,56,58] fair in eleven articles [26,29,31,35,39,41,50,51,53,54,57] and poor in two articles [43,44] (Appendix A). Total scores ranged between 4.5 and 12.5. Item five (power analyses, effect size calculation) was most frequently scored absent. Next, many studies did not provide sufficient details on the psychometric properties of the used

Table 1
Participant and study characteristics of the included studies.

Author(s)	Type participants	Baseline assessment	Mean age at baseline ±SD (range)	Outcome assessment	Mean age at outcome ±SD (range)
Barnett et al., 2003 [52]	FT infants with neonatal encephalopathy	GMDS <-1SD subtests (1) Locomotor Scale, (2) Eye-hand Scale	12m (9m −15m), 24m (21m−27m)	M-ABC-I Total Score Pc < 15	5.5y − 6.5y
Bruggink et al., 2008, 2009 [27,28]	PT infants (GA<32w)	GmA by Prechtl: quality of GMs MOS	6-10w, 11-16w, 17-21w	cMND by Examination of the child with MND (1979) and subcategories: (1) Posture and muscle tone, (2) Reflexes, (3) Choreiform dyskinesia, (4) Coordination and balance, (5) Fine manipulative ability, (6) Rare dysfunctions (incl. excessive associated movements).	7-11y
Danks et al., 2012 [56]	PT non-disabled ELBW (BW < 1000g)	NSMDA Total score and subtests: (1) Gross motor skills, (2) Fine motor skills, (3) Neurological status, (4) Postural reactions, (5) Sensory motor function	8m, 2y, 4y	M-ABC-I Total score Pc < 5	Mean 12.4m ± 0.70m (11-13y)
Eldred et al., 2010 [59]	Convenience sample of infants without developmental concerns	PDMS-I and PDMS-2 Pc ≤ 16 subtests (1) Fine Motor Scale, (2) Gross Motor Scale	9m, 11m, 13m, 16m, 21m	PDMS-2 Pc ≤ 16 Gross Motor Scale	5y, 5.5y
Evensen et al., 2009 [41]	Mixed group of prematurely born children with VLBW, FT children with SGA and FT controls with normal BW.	BSID-I PDI <2SD	1y	PDMS-I Pc ≤ 5 on ≥1 subtest (norms calculated by control group)	5y
Fjørtoft et al., 2015 [29]	VLBW infants (<1500g)	GmA by Prechtl: quality of GMs MOS	14w	M-ABC-2 Total Score Pc ≤ 16	10-11y
Goyen et al., 2008 [50]	Apparently normal high-risk children attending normal school (PT NICU infants) and controls (unclear if controls were included in predictive analysis)	GMDS Pc < 43 on subscales (1) Locomotor scale, (2) Eye-Hand scale PDMS-I subscales (1) Pc < 27 Fine motor, (2) Pc < 41 Gross motor	1y, 3y 3y	Indication of DCD defined as M-ABC-I Pc < 15	High-risk group: mean 8,8y ±0.3; Controls: mean 8,8y ± 0,4
Goyen et al., 2002 [49]	Apparently normal high-risk infants (GA <29w or BW < 1000g) attending normal schools	PDMS-I mild-significant deficit (undefined) at subtest (1) Gross Motor Scale, (2) Fine Motor Scale	18m CA, 3y	PDMS-I subtests (1) Gross Motor Scale, (2) Fine Motor Scale	5y
Griffiths et al., 2017 [55]	VPT infants (GA<30w)	M-ABC-2 Total score Pc ≤ 5 and Pc ≤ 15	4y 4m (4y - 5y5m)	M-ABC-2 Total Score Pc ≤ 5 and Pc ≤ 15	7y 11m (7y - 9y9m)
Groen et al., 2005 [30]	High-risk (PT-birth associated problems or FT with HIE and low-risk infants	GmA by Hadders-Algra: Quality of GMs	<38w PMA, 38w -7w PMA, 8-17w PMA	cMND by 'Examination of the child with Minor Neurological dysfunction'.	Controls: mean 137m (113 −150); Term high-risk: mean 111m (107−118); PT high-risk: mean 115m (108−126)
Grunewald et al., 2014 [31]	ELBW children (BW < 1000g)	GmA by Prechtl: Quality of GMs MOS	14w (±1,6w)	M-ABC-2 Beery−VMI-4	10y 2m ± 0,8m
Hadders-Algra et al., 1999, 2004 [32,33]	High-risk (FT with HIE or PT with neonatal complications) and low-risk children (FT without complications)	GmA by Hadders-Algra: Quality of GMs MOS	36w PMA - 8w post-term, 8-17w post-term	cMND by 'Neurological Examination of the Child with Minor Neurological Dysfunction'	Median 5‰(4-9y)
Hamer et al., 2016 [34]	Children with definitely abnormal Gms in infancy	GmA by Hadders-Algra: frequency of GMs	Median 10w CA (9-13w)	DCD-Q VABS Total Index Score <85	Median 8y4m (7y6m - 10y1m)
Hemgren et al., 2008 [57]	NICU children (PT and FT) without major impairments	CAMPB	3y CA (±1mo)	Moderate DCD (Pc < 15 TOMI + Floor level MPU <4y + No general medical condition, PDD or mental retardation with floor level MPU <3y) Definite DCD (Pc < 5 TOMI + Floor level MPU <4y + No general medical condition, PDD or mental retardation with floor level MPU <3y)	6.5y CA ±1m
Hitzert et al., 2014 [35]	FT healthy children (Overlapping cohort with Roze et al., 2010)	GmA by Prechtl: Quality of GMs MOS	Median 12.9 w (9,3 −18,6w)	M-ABC-I-NL Total Score Pc < 15 and Pc < 5 NEPSY-II Copy Design Task Pc < 15 DCD-Q	Median 5y11m (5y8m - 7y6m)
Howe et al., 2016 [47]	PT LBW children (GA ≤32w; BW ≤ 1500g)	AIMS BSID-II PDI	12m CA and 18m CA 12m, 18m and 24m	M-ABC-I Total Score Pc 5−15 and Pc < 5 VABS − Chinese version: subtest motor adaptive skills	60.21mo ± 1.87mo
Janssen et al., 2016 [46]	VPT children (GA<32w) without severe impairment admitted to NICU	BSID-II (American Version) PDI ≤69 and PDI 70-84	6m1w (±2w), 12m0w (±2w), 24m3w (±3w)	M-ABC-2-NL Pc < 15	63m1w ± 4w

(*continued on next page*)

Table 1 (continued)

Author(s)	Type participants	Baseline assessment	Mean age at baseline ±SD (range)	Outcome assessment	Mean age at outcome ±SD (range)
Janssen et al., 2009 [45]	PT infants (GA ≤32w) admitted to NICU	BSID-II PDI <85 and PDI <90 + subtest Behavior rating scale: motor quality (Pc ≤ 10: Non-optimal behavior, Pc11-25: questionable behavior, Pc ≥ 26: within normal limits behavior)	29m CA (±4,9)	M-ABC-2-NL Pc < 15	64m ± 2,3m
Long et al., 2016 [48]	Children with Cardiac heart disorder who underwent cardiac surgery in the first 2 months of life	AIMS Pc < 25 BSID-III	4m, 8m, 12m, 16m 2y	BOT-2-Short Form Total Score SS <-1SD	5y8m ± 3m
MacCobb et al., 2005 [40]	FT low-risk first-pregnancy infants	NBAS subtest Muscle tone and physical movements (= motor scale) BSID-I	3d and 21d 18m	BOT-MP Total Score SS ≤ 42	9y
Mazer et al., 2010 [42]	Mainly FT children with congenital anomalies admitted to ICU without major chromosomal or syndromal abnormalities	BSID-I-NL PDI score <84	6m CA, 12m CA, 24m	M-ABC-I-NL Pc ≤ 15	5y
Peyre et al., 2018 [54]	Mainly FT children	NEPSY-I: Copy Design Task ASQ-3 subtests (1) Fine motor skills, (2) Gross motor skills	3y	NEPSY-I: Copy Design Task ASQ-3 subtests (1) Fine motor skills, (2) Gross motor skills	5-6y
Piek et al., 2008 [53]	Low risk children	ASQ subtests (1) Fine motor skills, (2) Gross motor skills	4m, 6m, 8m, 12m, 16m, 18m, 20m, 24m, 30m, 36m, 48m	MAND subtests: (1) Fine motor, (2) Gross motor	8y 5m ±1y9m (6y0m − 11y 6m)
Roze et al., 2010 [36]	Healthy FT singletons (overlapping cohort study Hitzert et al., 204)	GmA by Prechtl: quality of GMs MOS BSID−II−NL Pc > 5 - ≤15 (suspect) and Pc ≤ 5 (abnormal)	12w (11-13w) 18m (17m3w - 18m1w)	M-ABC-I-NL Pc > 5 - ≤15 (suspect) and Pc ≤ 5 (abnormal)	6y1m (5y8m - 7y-6m)
Seme-Ciglenecki, 2007 [37]	High-risk PT children (GA<37w)	GmA by Prechtl: Quality of GMs	12w CA	cMND by Modified Partial Touwen test (Based on Examination of the child with minor neurological dysfunction 2nd edition by Touwen, 1979)	6y CA
Siegel, 1983 [43]	Mixed group PTs and FTs	BSID-I <-1SD	4m, 8m, 12m, 18m, 2y	McCarthy Scales of Children's Abilities motor scale score<85 Beery-VMI ratio-scores	5y
Siegel,1992 [44]	PT and matched FT children	BSID-I Kohen-Raz score (Average and below average)	4m, 8m, 12m, 18m, 2y	Beery-VMI	8y
Sustersic et al., 2012 [26]	PT infants	GmA by Prechtl: Quality of GMs	40w CA (±5days) (0-20w), 3m CA (0-20w)	Motor difficulties consistent with DCD by M-ABC-I Pc < 15	5-6y
Van Iersel et al., 2016 [38]	FT infants with and without difficulties at birth	GmA by Hadders-Algra: Quality of GMs	Median 3w CA (38-47w), Median 13w CA (48-58w)	cMND by 'Neurological Examination of the Child with Minor Neurological Dysfunction' M-ABC-I-NL Pc ≤ 15 (total score) or Pc ≤ 5 (subtest)	total group: median 77,5 m (75−83); DBAT group: median 77m (75−83); Non-DBAT group: median 77,5 m (74−81)
Wolthuis-Stigter et al., 2017 [58]	PTs (GA<36w) without major congenital defects and syndromes	NOMAS	37-40 PMA (weekly) and 42-50w PMA (two-weekly)	M-ABC-I-NL	5y8m (5y6m - 5y11m)
Yuge et al., 2011 [39]	PT and FT infants admitted to hospital due high-risk perinatal histories, abnormal findings pediatric examination or parental concerns	GmA by Prechtl: Quality of GMs MOS	Median 17w (9-21w)	DCD (unspecified how diagnosis was made)	5y

I/II/III= First, second or third edition, AIMS = Albert Infant Motor Scale; ASQ = Ages and Stages Questionnaire; Beery-VMI= Beery-Buktenica Developmental test of Visual-Motor Integration; BOT-(MP) = Bruininks-Oseretsky Test − (of Motor Proficiency); BSID(-NL) = Bayley Scales of Infant Development (Dutch version); (E/V) (L)BW= (Extremely/Very) (Low) Birth weight; CA= Corrected Age; CAMPB= Combined Assessment of Motor Performance and Behavior; d = day(s); DBAT = Difficult Birth at Term; DCD-(Q) = Developmental Coordination Disorder - (Questionnaire); FT= Full term; g = grams; GA = Gestational Age; GMs = General Movements; GmA = General movements Assessment; GMDS = Griffiths Mental Development Scales; HIE= Hypoxic Ischemic Encephalopathy; (N)ICU= (Neonatal) Intensive Care Unit; m = month(s); M-ABC(-NL) = Movement Assessment Battery for Children (Dutch Version); MAND = McCarron Assessment of Neuromuscular Development; (c)MND= (Complex) Minor Neurological Dysfunction; MOS = Motor Optimality Score; MPU = Motor-Perceptual Development; NBAS= Neonatal Behavior Assessment Scale; NEPSY = developmental Neuropsychological assessment; NOMAS= Neonatal Oral Motor Assessment Scale; NSMDA= Neuro-Sensory Motor Developmental Assessment; Pc = Percentile; PDD= Pervasive Developmental Disorder; PDI= Psychomotor Developmental Index; PDMS= Peabody Developmental Motor Scales; PMA= Post menstrual age; (V)PT= (Very)Preterm; SD= Standard Deviation; SGA= Small for Gestational Age; SS= Standard Score; TOMI = Test Of Motor Impairment; VABS= Vineland Adaptive Behavior Scale; w = week(s); y = year(s).

assessments. Due to relatively small sample sizes, regression analyses could not always be performed. Finally, the assessors were very rarely blinded to participant characteristics or previous assessment performances. The two poor-quality studies were the oldest included studies and only reported weak but significant correlations regarding the BSID-I. Concerning GmA, a slightly

higher study quality was found for studies applying the GmA by Hadders-Algra's method compared to GmA by Prechtl's method. Nevertheless, no strong associations were observed between study quality and the strength of the reported predictive values.

3.2. Predictive values grouped by outcome

Outcome measures were defined as DCD, cMND and significant motor delays on a standardized assessment. Fig. 2 depicts the significance of prediction grouped by outcome.

3.2.1. DCD

The outcome measure was defined as DCD in only two studies [39,57] and as probable DCD in another two studies [26,50]. Probable DCD was based on a score below the 15th percentile on the M-ABC while also considering the exclusion criteria. A total of five baseline assessment instruments were used in these studies.

3.2.1.1. Combined Assessment of Motor Performance and Behavior (CAMPB).
The included data of one study may suggest some evidence for the predictive value of CAMPB (Appendix B - Table 4). Neonatal Intensive Care Unit children with incoordination at 3y seemed to be three to five times more likely to develop DCD at 6.5 y [57]. DCD was defined as a score below the 15th percentile on the Test of Motor Impairment and a developmental delay in the area of Activities of daily living measured with the Motor-Perceptual Development (MPU). Additionally, these children did not have a general medical condition, pervasive developmental disorder, or mental retardation [57].

3.2.1.2. Griffiths Mental Development Scales (GMDS) — locomotor and eye-hand scale.
The included data of one study may suggest some evidence for the predictive value of the motor subtests of the GMDS in relation to probable DCD (Appendix B - Table 5). Goyen et al. reported a significant association in preterm children scoring below the 43rd percentile only on the locomotor scale at 3y, but not on the eye-hand-scale [50].
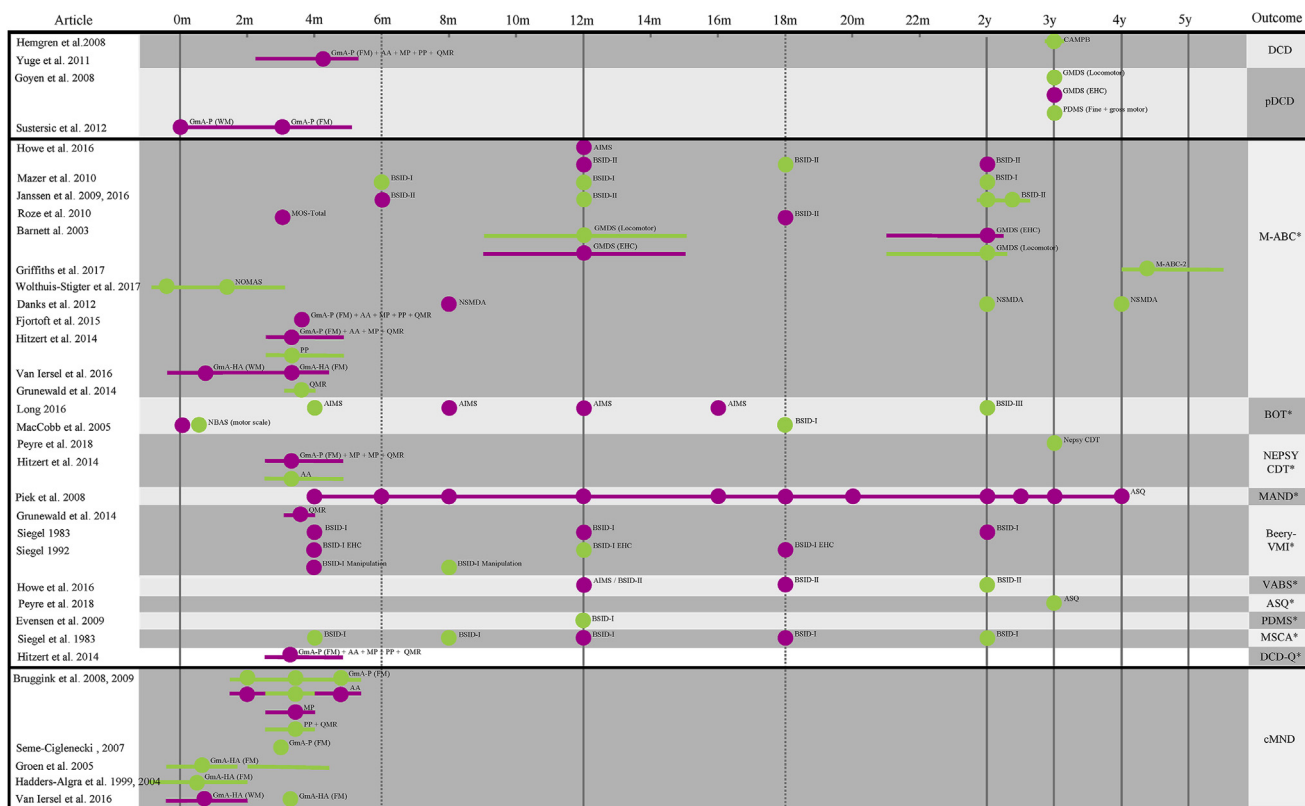
3.2.1.3. Peabody Developmental Motor Scales (PDMS).
The included data of one study may suggest some evidence for the predictive value of the PDMS in relation to probable DCD (Appendix B - Table 13). Three-year-old children scoring below the 27th percentile on the fine motor scale or below the 41st percentile on the gross motor scale were more likely to have probable DCD at 8 y [46].

3.2.1.4. General Movements Assessment (GmA) including Motor Optimality Score (MOS).
Two methods are available within GmA: Prechtl's method (GmA-P) and Hadders-Algra's method (GmA-HA). Both methods offer the possibility to observe the quality of general movements over three age-periods namely preterm, writing, and fidgety age. The MOS is an addition to the standard GmA and consists of five subtests: 'Quality of fidgety movements', 'Age-adequacy', 'Presence and normality of individual movement patterns', 'Presence and normality of individual postural patterns', and 'Quality of the motor repertoire'.

The included data of two studies suggest no significant evidence for the predictive value of the quality of writing movements or fidgety movements in relation to DCD [39] or probable DCD [26], nor was there evidence for the predictive value of any of the MOS

Fig. 2. Significance of prediction of a low motor score before five years of age in relation to DCD, pDCD, significant motor delay on a standardized assessment(*), and cMND after five years of age.

subscales in relation to DCD [39] (Appendix B - Tables 6—8).

3.2.2. cMND

The outcome measure was defined as cMND in five studies [27,28,30,32,33,37,38]. A total of two baseline assessment instruments were used in these studies.

3.2.2.1. General Movements Assessment (GmA) including Motor Optimality Score (MOS). The included data of five studies suggest some evidence for the predictive value of the quality of general movements in relation to cMND (Appendix B - Tables 6—8).

Data on the quality of writing movements in relation to cMND was only available using Hadders-Algra's method. Results from all three studies applying GmA-HA indicate that children presenting with definitely abnormal writing movements were more likely to develop cMND [30,32,33,38]. However, confidence intervals of relative risks were very wide. Additionally, Van Iersel et al. reported an association between mildly/definitely abnormal writing movements and subsequent dysfunctional domains of 'Posture and tone' and 'Coordination' at 6y after correcting for confounding variables [38]. Data on the quality of fidgety movements in relation to cMND was available in two studies using GmA-P [27,28,37] and three studies using GmA-HA [30,32,33,38]. In all studies but Van Iersel et al. [38], children with either abnormal/absent (GmA-P) [27,28,37] or definitely abnormal (GmA-HA) [30,32,33] fidgety movements appeared more likely to develop cMND. Yet again, confidence intervals were very wide. Furthermore, Van Iersel et al. reported an association between definitely abnormal fidgety movements and a subsequent dysfunctional domain of 'posture and tone' [38].

The included data of one study suggest only minor evidence for the predictive value of the MOS. Subtests 'Age-adequacy' and 'Quality of motor repertoire' at 11-16 weeks (w) seem related to cMND, but the 'Presence and normality of movement or postural patterns' are not [27,28].

3.2.3. Motor delays on a standardized assessment

School-aged motor delays were described using the M-ABC in eleven studies [29,31,36,38,42,45—47,52,55,56,58], the Bruininks-Oseretsky test (BOT) in two studies [40,48], the NEPSY Copy Design Task in two studies [35,54], and the Beery - Developmental test of Visual-Motor Integration (Beery-VMI) in three studies [31,43,44]. Predictive values were available only once for the McCarron Assessment of Neuromuscular Development (MAND) [53], VABS [47], ASQ [54], PDMS [41], McCarthy Scales of Children's Abilities (MSCA) [43], and DCD-Questionnaire (DCD-Q) [35]. A total of ten baseline assessment instruments were used in these studies.

3.2.3.1. Ages and Stages Questionnaire (ASQ) and NEPSY Copy Design Task. The included data of two studies may suggest some evidence for the predictive value of ASQ scores, but not for ASQ trajectories (Appendix B - Table 1). In low-risk children of whom parents completed eleven ASQ's between the age of 4m and 48m, no significant association could be withheld between the ASQ trajectories (i.e. age at which child reaches maximum performance, the maximum or minimum score, and the variance of ASQ scores) and MAND-scores at 6-11 y [53]. However, another study with a larger sample of low-risk children applying a novel edition of the ASQ, described that children scoring below the 10th percentile on either the ASQ-3 (fine or gross motor subtest) or the NEPSY Copy Design Task at 3y, were three times more likely to retain the poor performances at 5-6 y [54]. Relative risk confidence intervals were narrow and regression analysis supported the predictive value of the NEPSY Copy Design Task, the ASQ-3-fine motor, and the ASQ-3-gross motor.

3.2.3.2. Alberta Infant Motor Scale (AIMS). The included data of two studies suggest conflicting evidence for the predictive value of AIMS (Appendix B - Table 2). Long et al. reported an association between AIMS-scores at 4m, but not 8m, 12m, or 16m and BOT—SF—scores in children with congenital heart disorders at 5-6 y [44]. Yet, in preterm low birth-weight (LBW) children, AIMS-scores at 12m were not significantly associated with M-ABC-I total scores at 5y after correcting for confounding variables [47].

3.2.3.3. Bayley Scales of Infant Development (BSID). The included data may suggest some evidence for the predictive value of the Psychomotor Developmental Index (PDI) of the BSID first edition in five studies, the second edition in four studies, and the third edition in one study (Appendix B - Table 3).

Using the first version, significant associations were reported in all five studies although the studies of Siegel and MacCobb et al. could explain only a limited amount of the variance in school-aged performances on the BOT-MP [40], the MSCA motor scale [43], and the Beery-VMI [43,44]. PDI-scores at 6m, 12m and 24m were strongly associated with lower M-ABC-I-scores at 5y in term-born children with congenital anomalies [42]. Additionally, Evensen et al. retrieved significant results in relation to PDMS-I-scores at 5y in the very low birth-weight group (VLBW) but not in the small-for-gestational-age group or control group at 12 m [41].

Using the second version, significant associations were reported in three out of four studies. At 6m no significant associations were withheld in relation to school-aged M-ABC-2-scores at 5 y [46]. At 12m Janssen et al. [46] detected an elevated risk for poor M-ABC-scores at 5y in preterm children while Howe et al. [47] did not. No significant association was withheld at 12m or 18m with the Chinese Vineland Adaptive Behavior Scales scores (VABS-C) at 5 y [47]. At 18m, Howe et al. [47] reported a significant association to M-ABC-I-scores at 5y while Roze et al. [36], who studied low-risk children at 5-7y, did not. At 24m, preterm children with a low PDI were twice more likely to experience low M-ABC-2-scores at 5 y [46]. In contrast, Howe et al. only withheld significant results regarding VABS-C scores and not M-ABC-I-scores [47]. At 29m, Janssen et al. [45] detected that preterm children with a low PDI were twice more likely to experience low M-ABC-2-scores at 5y. Demonstrating low motor quality on the behavior rating scale of the BSID-II also yielded significant higher odds.

Using the third version, the motor composite score at 2y explained 39% of the variance in BOT—SF—scores score at 5y8m in children with a congenital heart disorder, whereas the gross motor score explained 29% [44].

3.2.3.4. Griffiths Mental Development Scales (GMDS) — locomotor and eye-hand scale. The included data of one study may suggest some evidence for the predictive value of the motor subtests of the GMDS (Appendix B - Table 5). Full-term children with neonatal encephalopathy and low scores on GMDS locomotor scale at 1y, but not 2y, and eye-hand scale at 2y, but not 1y, seemed more likely to have low M-ABC-I-scores at 5-6 y [52]. However, confidence intervals were wide.

3.2.3.5. General Movements Assessment (GmA) including Motor Optimality Score (MOS). The included data of three studies suggest no evidence for the predictive value of the quality of general movements in relation to motor delays on a standardized assessment at school-age (Appendix B - Tables 6—8). The quality of writing movements by GmA-HA was not associated to M-ABC-I total score or any of its subtests at 6 y [38]. The quality of fidgety movements by GmA-P [29,35] or GmA-HA [38] was not associated to M-ABC-I [35], M-ABC-2 [29], NEPSY-II Copy Design Task [35] or DCD-Q [35].

The included data of four studies suggest only minor evidence for the predictive value of the MOS. The MOS total score explained merely 4% of the variance of the M-ABC-I scores at 5-7 y [36]. Nor 'age-adequacy' nor 'the presence and normality of movement patterns' were related to M-ABC-I at 5-7 y [35], M-ABC-2 at 10-11 y [29], or DCD-Q at 5-7 y [35]. Only Hitzert reported a weak association between 'age-adequacy', but not 'normality of movement patterns', and the NEPSY-II Copy Design Task at 5-7y. The 'presence and normality of postural patterns' could be related to M-ABC-I at 5-7 y [35], but not to M-ABC-2 at 10-11 y [29], NEPSY-II Copy Design Task at 5-7 y [35], or DCD-Q at 5-7 y [35,39]. 'The quality of the motor repertoire' was not related to M-ABC-I, NEPSY-II Copy Design Task, or DCD-Q at 5-7 y [35]. A significant association to M-ABC-2 total score at 10y was reported by Grunewaldt et al. [31], but not by Fjørtoft et al. at 10-11 y [29]. Additionally, Grunewaldt et al. reported a significant association with the M-ABC-2 subtest 'balance', but not with 'manual dexterity' or 'aiming and catching' [31].

3.2.3.6. Movement Assessment Battery for Children — second edition (M-ABC-2). The included data of one study may suggest some evidence for the predictive value of M-ABC-2 in very preterm children (Appendix B - Table 9). After correcting for confounding and missing variables, a low score on the M-ABC-2 at 4.4y seemed to explain 50% of the variance of the M-ABC-2 scores at 7y11 m [55].

3.2.3.7. Neonatal Behavioral Assessment Scale (NBAS) — motor scale. The included data of one study suggest minor evidence for the predictive value of NBAS at 21 days (d), but not at 3d (Appendix B - Table 10) [40]. The NBAS at 21d explained 12% of variance on the balance subtest of the BOT-2 at 9y in low-risk children and 27% of the variance after correcting for the child's responsiveness and body motion.

3.2.3.8. Neurological, Sensory, Motor, Developmental Assessment (NSMDA). The included data of one study may suggest some evidence for the predictive value of NSMDA at 2y and 4y, but not at 8m in preterm extremely low birth weight (ELBW) children [56] (Appendix B - Table 11). Children with a low NSMDA score at 2y or 4y were twice more likely to have low M-ABC-I-scores at 11-13y.

3.2.3.9. Neonatal Oral-Motor Assessment Scale (NOMAS). The included data of one study may suggest some evidence for the predictive value of NOMAS (Appendix B - Table 12). Wolthuis-Stigter et al. indicated that a normal sucking pattern in a mixed group of children at 50w post-menstrual age (PMA), but not 40w PMA, was associated with better M-ABC-I-scores 5y [58]. In contrast, children with prolonged definitely abnormal sucking patterns were more likely to experience low M-ABC-I-scores. Furthermore, moderate positive correlations were reported between several items of NOMAS and the balance subtest of M-ABC-I.

3.3. Predictive values grouped by age at baseline assessment

As depicted in Fig. 2, predictive results vary greatly in the first two years of life. Before 12m, the GmA and MOS subtests seem associated to cMND [27,28,30,32,33,38], but not to DCD [26,39] or motor delays on standardized motor assessments [27—29,35,36,38]. NOMAS [48,58] was related to school-aged motor delay while inconsistent results were obtained regarding AIMS [47], NBAS motor scale [40], and BSID [42—46]. As children age, predictive values tend to improve. Associations between BSID and motor outcome demonstrate significant results in four [41,42,44—47] out of six studies [43,47] at 12m, two [40,47] out of five studies [36,43] at 18m and in all five studies at 2 y [42-48]. Similarly, the NSMDA was only associated to school-aged M-ABC-I-

scores at 2y and 4y, but not at 8 m [56]. At 3y, an association was reported between (probable) DCD and the scores on the PDMS [50], the GMDS Locomotor scale [50], and the CAMPB [57]. Furthermore, NEPSY Copy Design task and ASQ [54] seem valuable in predicting significant motor delays. Lastly, M-ABC-2 between 4.5 and 5.5y likewise showed promising results in predicting school-aged motor delays on standardized motor tests [55].

3.4. Summary

The GmA seems to be of modest value in the prediction of cMND, but not for other motor outcomes or (probable) DCD. Regarding the prediction of school-aged motor problems, other than cMND, the ratio sensitivity/specificity was best in BSID-I at 1y (67/100) [41] and M-ABC-2 at mean age of 4.4y (72/93) [55] with the latter presented in a higher quality study. Sensitivity was found highest for PDMS at 3y (94%) [50] and BISD-II at 1y (93%) [46], while specificity was found highest in BSID-I at 1y (100%) [41] and GMDS locomotor scale at 1y (100%) [52]. The ratio NPV/PPV was best in BSID-I at 1y (100/93) [41] and GMDS Locomotor scale at 1y (100/80) [52] with the latter presented in a higher quality study. PPV was found highest for BSID-I at 1y (100%) [41] and GMDS locomotor scale at 1y (100%) [52], while NPV was found highest in CAMPB at 3y (96%) [57], M-ABC-2 at mean age of 4.4y (93%) [55] and BSID-I at 1y (93%) [41]. The ability to detect motor problems seems to be elevated in high-risk groups and increases as children grow older. The number of studies specifically investigating associations between early motor development and subsequent DCD is very limited.

4. Discussion

4.1. Main findings

This review aimed to summarize which standardized motor assessments before the age of five are available to accurately predict DCD, cMND, and significant motor delays on a standardized assessment in children aged five to twelve years. The majority of early motor assessments included in this review seem to have some predictive value for school-aged motor problems. This finding indicates that motor problems relating to DCD may already be detectable early in life. Nevertheless, no assessment instrument reached the recommended 80% sensitivity and specificity [60] and merely four studies specifically reported (probable) DCD as outcome. Together with the large clinical heterogeneity and the great variety in assessment instruments, applied cut-offs, reported terminology and statistical methods, this makes it very difficult to compare studies and draw solid conclusions.

Importantly, only two studies reported DCD as a distinct outcome measure. The motor assessments suggested by the EACD to aid in operationalizing criterion A of the DSM-5 [1] are M-ABC-2 and BOT-2 whereas the DCD-Q has been suggested for criterion B [2]. However, diagnostic criteria of DCD are still open for interpretation and are not always well-described in research settings. Only Hemgren et al. [57] considered all diagnostic criteria, while Yuge et al. [39] did not elaborate on how the children were diagnosed. Another two studies reported 'probable DCD' based on a total M-ABC score below the 15th percentile [26,50]. Although both studies excluded children with other disorders possibly responsible for the motor delay (criterion D), they did not account for criterion B. These four studies suggest some minor evidence that the CAMPB at 3 y [53], the GMDS locomotor scale at 3 y [46], and the PDMS at 3 y [46] may have some predictive value for (probable) DCD, while the GmA and MOS do not [26,39]. However more longitudinal studies starting in infancy with well-applied diagnostic criteria for

DCD or clinical diagnoses are necessary.

MND is an often reoccurring outcome measure in the included studies. Although a relation has been described between MND and DCD, the mechanisms for this relationship are still unclear. We cannot assume that all children with cMND fulfill the diagnostic criteria for DCD, although an important part of them will [14]. This review adds to that discussion given that GmA and MOS appeared associated to cMND, but not to DCD or low scores on the M-ABC-2, the most widely used assessment instrument in the DCD field. As GmA and cMND focus on central nervous integrity, the M-ABC-2 evaluates several specific functional motor skills, which might explain the lack of association between GmA and M-ABC-2 [36]. Prediction of school-aged cMND was solely investigated using GmA or MOS in early infancy. Using Prechtl's method, absent and abnormal fidgety movements seemed related to cMND whereas in Hadders-Algra's method, definitely abnormal fidgety movements seemed associated to cMND. Although confidence intervals were quite large, prompting for careful interpretation, this finding is somewhat surprising, as abnormal fidgety movements have previously been associated in a greater extent with CP [38]. As this review exclusively included data of children without CP, this might have shifted the observed associations. The results of this review indicate the presence of a certain association between GmA and MOS in early infancy and school-aged cMND, albeit more research is necessary to explore the concept of MND and its relation to DCD.

The majority of the included studies investigated the association between early motor assessment and significant motor delays at school-age measured with a standardized assessment. In the studies that provided sufficient data to calculate sensitivity and specificity, the BSID-I and BSID-II showed the highest sensitivity [46] and specificity [41] respectively. The ratio sensitivity/specificity is also highest in the BSID-I [41] and the M-ABC-2 [55]. The only included study applying the BSID-III was able to explain a large part of the variance in school-aged BOT-2-scores, but did not offer data to calculate sensitivity and specificity. Still, this study comprised children with congenital heart disorders, so generalization of these findings is limited as it possible that the experienced motor problems may be explained by other factors. Nevertheless, as the first editions of the BSID do suggest some promising results and strong correlations have been reported between the BSID−II−PDI and Bayley-III motor composite score [61], BSID-III might also be valuable in detecting early motor problems starting at the age of 1m. Recently, the new BSID-IV was published, but no information is available yet on its predictive value. The M-ABC-2 is a suitable assessment instrument starting at 3 y [55]. However, the relatively good predictive values were not surprising as it was the same test which was used, only a few years later. The GmA did not seem associated to motor delays at school-age in this group of non-CP children. A 2011 systematic review proposed that GmA might not sufficiently tap into the areas necessary to detect more subtle impairments [62]. Some suggest that motor delays in this group of children may not be apparent this early in life when motor demands are less complex. Nevertheless, NOMAS at 37-50w PMA [58], the NBAS at 21 d [40], and the AIMS at 4m could all be related to school-aged motor performance.

Remarkably, only one parental questionnaire, the ASQ, was applied before 5y. Piek et al. was unable to detect significant associations between ASQ-trajectories and a subsequent lower MAND-score at school-age [53], while Peyre did reported significant associations between ASQ at 3y and ASQ at 5-6y. This association is not surprising as the outcome measure was the same. Although the ASQ is a reliable and valid questionnaire, doubts about the reliability of parental questionnaires in children with DCD have been reported [63]. It would be interesting to investigate the predictive value of parental questionnaires specifically designed for detecting DCD before 5y such as the Little-DCD-Questionnaire. More research is necessary to clarify the relationship between infant motor development and motor delay at school-age.

It is clear that prediction of school-aged motor outcome poses a complex and difficult challenge. Accordingly, EACD-guidelines suggest to only diagnose DCD before 5y of age when repeated assessments indicate motor problems. Many studies report high variability in longitudinal motor performance as a typical developmental trait and emphasize that one should cautiously interpret results from a single assessment in time [64−66]. Indeed, manifold low motor scores strengthen the predictive values of later developmental outcomes [47,51,67]. A combination of diverse assessments or sequential screening [68] might be extremely valuable in improving the predictive accuracy. Hemgren et al. reported better predictive values for DCD when combining both motor incoordination and inattention [57]. Additionally, Spittle et al. demonstrated a consistently higher accuracy when combining results of the AIMS and the NSMDA in the prediction of low M-ABC scores at 4 y [67].

As children grow older, predictive values tend to improve. This may be explained by various reasons. Firstly, a possible catch-up effect should be considered, especially in very preterm children during the first year of infancy [69]. Secondly, Goyen et al. suggest that children may present with more motor problems as their age increases because of the augmented complexity of test items [49]. Therefore, children might grow into motor problems due to higher demands of complex neurological functioning [70]. Finally, one has also to keep in mind that prediction is greatly influenced by the psychometric quality of the chosen instrument. Moreover, test results are snapshots of the child's development and may be influenced by the child's mood, motivation, and health status. Hence, besides using a valid and reliable assessment instrument, clinical judgment remains important when assessing children [71]. The quality of movement, functional motor success, and parental concerns should also be considered [51,72].

4.2. Study strengths and limitations

Many studies were excluded since data was not provided for non-CP children. Although, Williams et al. [73] claim some sort of continuum between DCD and CP, they are two distinct conditions. It would be beneficial if studies would report separate results for these two groups as the prediction of CP is more straightforward and the inclusion of children with CP might cause inflated predictive values. We contacted authors to supply additional information on the non-CP group, which we believe is a vast benefit of this systematic review as novel data of this subgroup may provide new insights. A publication bias may be present as only published full-text were included. Additionally, we did not account for known risk-factors which may possibly influence the results. Although some studies accounted for confounding variables, this was not always the case. In addition, many studies included very specific populations and small sample sizes, limiting comparison and generalization of the results. Nevertheless, given the vast heterogeneity, a meta-analysis to account for these confounders was not appropriate. Many studies applied diverse assessment instruments over time, thus the inherent differences between assessment instruments may also explain part of the variance between scores at baseline and outcome assessment. However, these assessment instruments are widely accepted tools to identify children with motor problems and are applied similarly in follow-up programs. The vast majority of included studies assessed motor delay at school-age used a cut-off score of at least one standard deviation below the mean on the M-ABC or the BOT. In research settings, children are

often catalogued into the probable DCD-group based on a low motor score (criterion A). So, although these children were not formally examined for DCD and detected motor problems may be due to other reasons, it seemed valuable to include them in our review.

Given the extensive searches in seven different databases, we believe we have identified all of the existing literature. Yet ten studies were identified by applying backward and forward referencing, indicating we might have overlooked some studies. As we only included outcome assessments after the age of 5y, we might have missed important studies reporting predictive values for younger children.

Furthermore, the risk of bias of the included studies introduces another possible limitation. Few assessors were blinded to participant characteristics or previous assessment performances, and the majority of studies did not account for confounding variables, nor did they elaborate sufficiently on the psychometric properties of the applied assessment instruments.

4.3. Implication for clinical practice

Motor assessments before the age of five are valuable in detecting DCD, cMND, and motor delay. Repeated assessments over multiple developmental domains and time periods seem to enhance predictive accuracy. Based on the compiled data, we carefully suggest that in infancy, GmA may be useful in detecting cMND, but not DCD. As the previous editions of the BSID did suggest promising results, its novel edition might also be valuable in detecting motor delay. The M-ABC-2 seems valuable starting at 3y. More research is necessary to confirm these hypotheses.

5. Conclusion

As DCD is a heterogeneous disorder with many clinical appearances, the early developmental process may also vary considerably between individuals. No motor assessment instrument will ever be able to accurately identify all children with motor delay or DCD at school-age. At or before 2y of age, the BSID, motor subtests of GMDS, NOMAS and NSMDA seem valuable. More research is needed to determine the most appropriate assessment instrument in this age-group. Starting at 3y, the PDMS, motor subtests GMDS, NSDMA, M-ABC-2 and CAMPB show promising results. They seem particularly valuable in predicting which children will not develop DCD, cMND or motor delays. To conclude, the DCD-field necessitates more high-quality longitudinal studies including diverse assessments at multiple ages, starting in infancy, with attention to risk-factors, quality of movement, parental concerns and applying well-defined diagnostic criteria of DCD.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

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