Systematic review

JCHC

Journal of Child Health Care
2022, Vol. 0(0) 1–27

DOI: 10.1177/13674935221114187
journals.sagepub.com/home/chc
SAGE

The association between learning disorders, motor function, and primitive reflexes in pre-school children: A systematic review

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Abstract

This study aimed to systematically review evidence of the association between learning disorders, motor function, and primitive reflexes in preschool children. Seven databases were systematically searched (EMBASE, CINAHL, Academic Search Complete, Medline, PsycINFO, ScienceDirect, and Cochrane) with no restrictions. Inclusion criteria were full text peer-reviewed articles reporting new empirical data, assessing any two of three phenomena in preschool children: learning disorders, motor function, or primitive reflexes. Intervention studies or studies examining congenital, chromosomal or acquired neurological, or pathological conditions and prematurity were excluded. Included papers ($n = 27$) were assessed for methodological quality by the Hoy et al. Risk of bias tool. Learning and motor function were assessed in all except two articles and motor deficits found to be associated with speech/language and executive function as well as several areas of academic performance. Three studies included primitive reflexes, with high levels of the asymmetrical tonic neck reflex positively correlated with fine motor skills, "school readiness" and "impulsivity, hyperactivity and inattention." Caution must be used when interpreting the review results due to significant study heterogeneity. Further research is needed to further understand common underlying mechanisms that may inform earlier diagnostic methods for these three phenomena. PROSPERO: CRD42021265793

Keywords

Learning difficulties, primitive reflex, motor function, child development, child health

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Introduction

Learning disorders are usually diagnosed after a child has started formal schooling (Earls and Hay, 2006), where exposure to the environment in which they are incompetent highlights the individual's shortcomings (AUSPELD, 2019). This phenomenon does not go unnoticed by the child who, by 5 years of age, has capacity to compare their skill set to their peers (Piek et al., 2006). A range of negative outcomes accompany learning disorder diagnosis, with individuals reporting greater frustration and distress in school (Willcutt et al., 2011), social rejection and bullying by peers, diminished self-esteem and confidence, and potentially becoming withdrawn or acting out (Kiuru et al., 2012). Children with a learning disorder are also more likely to attain lower levels of education, in part due to lower high school completion rates, compared to those without learning difficulties (Willcutt et al., 2011). Diagnosis prior to formal schooling would limit exposure to this cascade of negative educational associations, and allow opportunity for early intervention and potentially prevention (Fletcher et al., 2006).

Learning disorders are one of the most frequently diagnosed developmental disorders of childhood (Moll et al., 2014), affecting approximately 10–16% of Australian students and a similar proportion worldwide (Elkins, 2002). Learning disorders create significant financial cost to public health and education systems (Willcutt et al., 2011). Defined as "an academic-based disorder originating in the central nervous system" (p. 27) (Scanlon, 2013), learning disorders are specific to one or more neurodevelopmental functions (e.g., speech, arithmetic, reading etc.). Despite research in this field historically focusing on deficits in a single domain, comorbid statistics suggest that multiple deficits are more common than singular deficits (Moll et al., 2014). Additionally, various disorders co-occur with learning disorders, including conduct disorder, anxiety and depression, attention deficit hyperactivity disorder (ADHD) (Willcutt et al., 2011), and developmental coordination disorder (DCD) (Sugden et al., 2008). With co-occurring disorders crossing several developmental domains, investigating motor and neurological factors may provide further insight into common underlying themes between their relationship and learning.

Both fine and gross motor function are essential for successful transition to the formal school environment, as they underpin most educational tasks, allowing physical independence (Bart et al., 2007; Strooband et al., 2020). Motor skills allow participation in essential play activities with peers, creating opportunities for children to socially interact and take manageable risks. In turn, play provides benefits of cognitive, social and further motor development, building self-esteem and self-control (Bundy et al., 2011). Historically, a variety of labels have described motor problems, however, since 1994 DCD has been preferred (Cairney et al., 2010). Classified as a neurodevelopmental disorder, DCD signifies delayed and immature motor ability and affects 5–20% of all children globally (Niklasson et al., 2017). While DCD does not include signs of intellectual impairment, certain comorbidities of cognitive function do occur (Niklasson et al., 2017) such as specific language impairment (SLI) (60%), reading difficulties (55%), and ADHD (60%) (Sugden et al., 2008). DCD has also been found in association with retained primitive reflexes (Niklasson et al., 2015).

Primitive reflexes are brainstem-mediated, automatic motor responses to specific sensory stimuli (Zafeiriou, 2004). At birth, primitive reflexes give rise to most movements of the newborn (Gallahue and Ozmun, 2006). Over time, with adequate sensory stimulation, neural pathways are generated, leading to reflex integration and thus reflexive motor function is replaced with conscious, controlled movement (Gallahue and Ozmun, 2006). Integration should occur during the first year of life (McPhillips and Jordan-Black, 2006). Primitive reflex development and subsequent integration assist an infant's development of physical independence through achievement of sequential motor milestones that progress to ambulation (Gallahue and Ozmun, 2006). For example, asymmetrical tonic neck reflex (ATNR) stimulation causes ipsilateral arm extension, preventing the infant rolling to that side (Konicarova and Bob, 2013). Sufficient ATNR integration inhibits arm extension, allowing the infant to roll (Zelazny, 1998). Traditionally, primitive reflex assessment is readily utilized to identify neurological pathology in the infant (Jordan-Black, 2005). However, employment of modified position testing in older age groups has shown persisting reflexes to be associated with reading difficulties and dyslexia (McPhillips and Jordan-Black, 2006), speech-language disorders (Adamovic et al., 2014), ADHD (Konicarova and Bob, 2013), and motor deficiency (DeGangi et al., 1980; Freides et al., 1980).

The ATNR is described as the most widely researched reflex in therapeutic literature (Gallahue and Ozmun, 2006). Despite other reflexes being investigated, many studies have reported results as a total reflex score, thus impeding identification of specific reflex impact (DeGangi et al., 1980; Freides et al., 1980; Niklasson et al., 2017). Whilst primitive reflexes have been found in association with individual motor deficits and learning difficulties, viewing the relationship between all three phenomena may provide insight into what common factors underlie these co-occurring disorders.

No systematic review has focused specifically on primitive reflexes and a small number of reviews assessing the relationship between motor function and learning disorders have predominantly focused on older age groups (Hill, 2001; Van der Fels et al., 2015). Further research is therefore required to expand our understanding of primitive reflexes and their relationship to motor function as well as learning disorders in the pre-school age group with a view to helping identify learning disorders prior to commencing formal schooling.

Aim

To evaluate literature reporting an association between learning disorders, motor function and primitive reflexes in pre-school aged children.

Methods

Registration

The protocol for this systematic review was developed and undertaken in accordance with Preferred Reporting Items for Systematic Review and Meta-analysis Protocols (PRISMA-P) 2020 statement (Page et al., 2021) and registered with the International Prospective Register for Systematic Reviews (PROSPERO) on 6th August 2021 [CRD42021265793] (McWhirter et al., 2021).

Search strategy

The PICOT model was used to determine search strategies derived from the question "What association exists between learning disorders, motor function and primitive reflexes in preschool children?" Seven databases were searched: (EMBASE, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Academic Search Complete, Medline, PsycINFO, ScienceDirect and Cochrane) according to Cochrane guidelines for systematic review, up until and including 8th April 2022. Keywords and MeSH headings related to three search hedges (learning disorder, primitive reflex, and motor function) were used and combined with Boolean operators (OR, AND) (Supplemental Figure 1).

Eligibility criteria

This review was limited to full text, peer-reviewed publications reporting new empirical data, encompassing any two of the three search hedges, in a pre-school cohort. As naming terminology and starting age for preschool varies significantly between countries, to ensure consistency of review inclusion, study participants include 3.0–6.11 years of age, unless the cohort is otherwise labeled within preschool parameters. Studies involving participants that were premature or possessed any serious neurological or pathological disorders, such as cerebral palsy, muscular dystrophy, or any congenital, chromosomal, or acquired abnormality impairing neurological and/or motor function were excluded. Excepting clinical trials and intervention studies, no restrictions were placed on study design, sample size, or language. Search terms aimed at capturing physically assessed gross motor over fine motor function; hence, studies only assessing fine motor skills or solely capturing motor skill via questionnaires were excluded from review.

Data extraction and quality assessment

Title, abstract, and full text screening of resulting articles was undertaken independently by two authors (KW and AS) to confirm eligibility criteria was met. Data extracted from each article included study design, setting, sample characteristics, outcome measures, and results. The Hoy et al. (2012), Risk of Bias Tool for Prevalence Studies was utilized to evaluate study quality regarding selection, non-response, measurement, and analysis bias. Consisting of a 10-item checklist corresponding to external (items 1–4) and internal validity (items 5–10), each item is rated as high or low risk. Where insufficient information is provided, a rating of high risk is given. The rater utilizes these 10-item ratings to subjectively determine overall risk of bias as either low, moderate, or high.

Results

Database searches yielded a total of 19,390 articles, which were uploaded into systematic review software, Covidence. After duplicates were removed, title and abstract screening identified 316 articles eligible for full text review, 294 of which were excluded with reasons documented. Four additional studies were discovered through targeted hand searching of reference lists. Focused citation tracing was undertaken using Google Scholar, resulting in one further paper. A total of 27 articles met eligibility criteria for inclusion for systematic review (Figure 1).

Participants and study characteristics

Study and sample characteristics are summarized in Table 1. Sample sizes ranged from 23 to 12,583 participants, aged between 2.8 and 7.3 years. Only male participants were included in two studies (Cameron et al., 2012; Muursepp et al., 2011) and another 18 studies included more male than female participants. Excepting control groups, sample populations were either diagnosed with a specific learning disorder ($n = 11$) or motor impairment ($n = 4$), from a disadvantaged ($n = 2$) or high socio-economic background ($n = 1$) or considered normal ($n = 11$). Publication years spanned

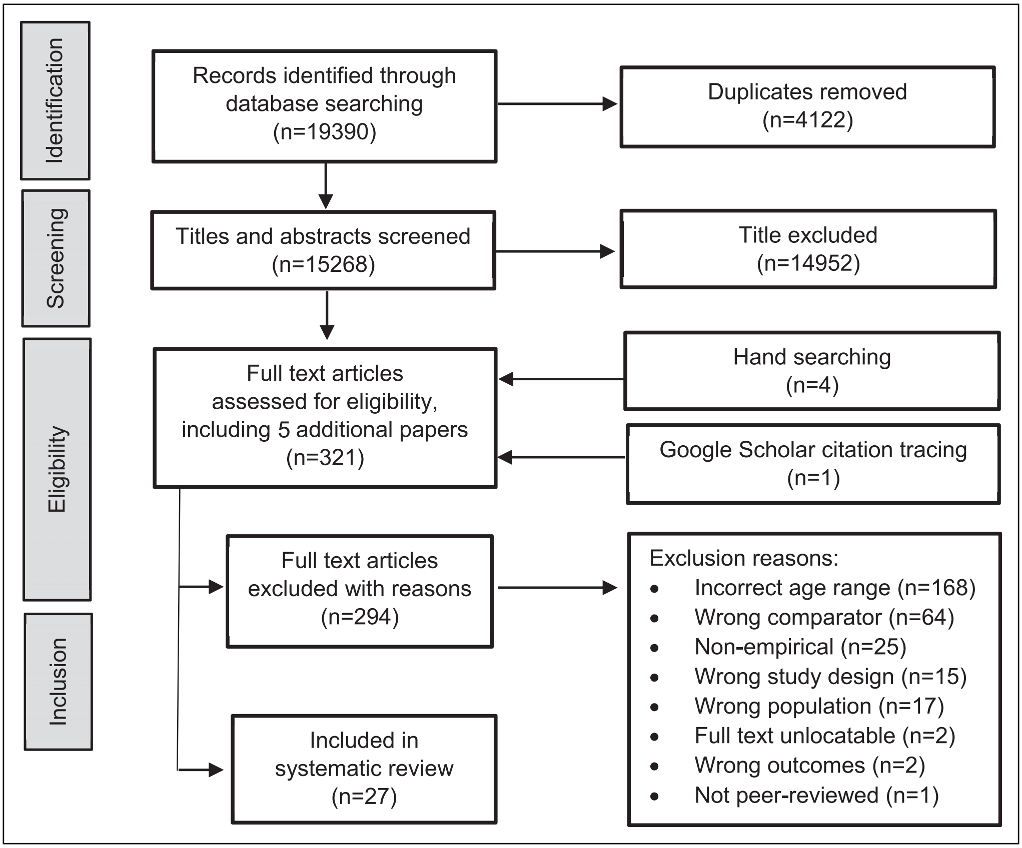

Figure 1. Preferred reporting items for systematic reviews and meta-analysis flow diagram of studies identified through the review process.

from 1995 to 2021 and research conducted in 12 different countries (USA, Estonia, Germany, England, Poland, Australia, Canada, Iran, Netherlands, South Africa, Greece, and Taiwan). All articles were published in English, except for one published in Farsi (Hasanati et al., 2010), and three published in German (Jascenoka et al., 2018; Kastner et al., 2011; Molitor et al., 2015), requiring translation.

Excepting two mixed-method designs (Callcott, 2012; Wassenberg et al., 2005), all studies utilized a quantitative approach. Study designs varied, including cross-sectional studies (n = 12), observational cohort studies (n = 2), case-control (n = 6), longitudinal studies (n = 4), and longitudinal/case-control (n = 3).

Risk of bias within studies

A risk of bias analysis for each of the 27 studies has been summarized in Supplemental Table 1. All studies were found to have low-moderate risk and were included in this review. Most studies did not provide information regarding whether target population represented national population or details

Table 1. Study characteristics and findings.

Authors, country, study design, recruitment	Participant characteristics	Outcome measurements compared	Results/Correlations
Asonitou et al. (2012), Greece, case-control, public Kindergartens	N = 108 73M, 35F (68% boys) Age 4.6–6.3 years DCD: n = 54 Non-DCD: n = 54	Motor (MABC) and Cognitive (EF: Das-Nagliere cognitive assessment system	DCD children performed at a lower level in all motor and cognitive tasks, compared to non-DCD children Total MABC score was significantly correlated with planning cognitive processing ($r = -0.276$, $p < 0.05$) Simultaneous cognitive processing and manual dexterity were significantly correlated for both DCD and non-DCD groups (DCD $r = -0.283$, $p < 0.05$; non-DCD $r = -0.211$, $p < 0.05$) Planning cognitive processing and balance were significantly related for the non-DCD group ($r = -0.31$, $p < 0.05$).
Callcott (2012), Australia, mixed methods, cross-sectional, catholic and metropolitan schools	N = 40 (Qualitative = 3) 20M, 20F (50% boys) Age: 4.6–5years Indigenous/ disadvantaged	Motor (MABC-2) and primitive reflex (ATNR)	ATNR significantly predictive of total MABC-2 scores [$R = 0.417$, $R^2 = 0.174$, R^2adj = 0.152, $F(1, 38) = 7.997$, $p = 0.007$] and manual dexterity scores ($R = 0.446$, $R^2 = 0.199$, R^2adj = 0.178, $F(1,38) = 9.460$, $p = 0.004$) No correlation shown between ATNR and aiming and catching [$R = 0.201$, $R^2 = 0.040$, R^2adj = 0.015, $F(1, 38) = 1.597$, $p = 0.214$] or ATNR and balance ($R = 0.261$, $R^2 = 0.068$, R^2adj = 0.044, $F(1, 38) = 2.784$, $p = 0.103$)
		Learning/Motor (teacher interviews regarding school readiness and work samples; MABC-2 Checklist) And primitive reflex (ATNR)	Teacher interviews and questionnaires reported "a definite trend to impulsivity, hyperactivity and inattention in all three children." (p138) All three children show a "lack of detail in their human figure drawings" (p137) and had difficulty with cutting and pasting

(continued)

Table 1. (continued)

Authors, country, study design, recruitment	Participant characteristics	Outcome measurements compared	Results/Correlations
Cameron et al. (2012), USA, longitudinal, Preschools	N = 213 100% boys Age-T1: 3.5–5.7years Age-T2: 4.6–6.2 years Advantaged and disadvantaged	Motor (ESI-R) [T1] and cognitive (academic knowledge: WJIII) [T2]	Higher GM and draw-a-person scores predicted greater fall-to-spring improvement in academic knowledge, however at the marginally significant level Higher FM scores achieved higher levels on WJIII assessment, except in applied problems (mathematics)
		Motor (ESI-R) [T1] and cognitive (EF: HTKS) [T2]	Total FM scores positively correlated with EF (HTKS) [$p < 0.01$]
Cheng et al. (2009), Taiwan, Cross-sectional, Not reported	N = 363 205M, 158F (57% boys) Age: 5–6 years Normal	Participants were identified as DSLD, DCD or neither using: Motor (MABC) and speech tests (composite speech/language tests, LAAP, PPVT-R)	DSLD and DCD were found to be significantly related [chi-square = 5.77, p = 0.289]. Children with DCD were three times more likely to be diagnosed DSLD than those children without DCD DSLD was associated with poorer scores on manual dexterity and total impairment score for MABC than non-DLSD participants [3.32 ± 2.59 vs 0.89 ± 1.39, $p < 0.0001$; 7.30 ± 5.80 vs 4.25 ± 3.78, p = 0.024]. A marginally significant difference was found between groups for balance [1.52 ± 2.30 vs 0.77 ± 1.60, p = 0.055]. No statistical significance was found between groups (DSLD v non-DSLD) for ball skills [2.45 ± 2.40 vs 2.59 ± 2.43, p = 0.816)

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Table 1. (continued)

Authors, country, study design, recruitment	Participant characteristics	Outcome measurements compared	Results/Correlations
De Waal (2019), South Africa, cross-sectional, one pre-primary school	N = 69 38M, 31F (55% boys) Age: 5–6 years High socio-economic background	Motor: (Kinderkinetics screening Assessment) and learning (academic performance: Mathematics, life orientation, Home language)	Of all motor skills, dynamic and static balance showed the largest correlations with academic performance, particularly mathematics [$p \le 0.05$] Star jumps correlated largely and significantly with mathematics performance and moderately with life orientation skills and home language [$p \le 0.05$] Fundamental locomotion skills correlated largely with mathematics and moderately with home language performance and life orientation skills [$p \le 0.05$] All three areas of GM correlated moderately with home language [$R > 0.3$, $p \le 0.05$]
DiDonato et al. (2014), USA, Case-control, Not reported	N = 23 M11, F12 (47% boys) Age: 4–6 years SLI: n = 11 Control: n = 12	Motor (Bruininks-Oseretsky test of motor integration or PDMS)	SLI group had significantly lower scores on motor scales compared to controls. [$F(1, 18) = 11.98$, $p = 0.003$] with similar results found for FM and GM 5 of the 11 (45%) children with SLI showed an overt motor impairment (≥1 SD below the mean on PDMS or Bruininks-Oseretsky)
Gaines and Missiuna (2006), Canada, observational cohort, toddler talk program	N = 40 27M, 13F (68% boys) Age: 5.3–6.8 years Speech language delay as toddlers	Motor (MABC-2) and speech/language (CELF-P-2, EOWPVT-R, GFTA-2, PPVT-III)	Significant motor impairment was identified in 18 (45%) children in the follow-up group. Of these children, 12 (66%) met all diagnostic criteria for DCD Within the DCD group, 9 (75%)) had either a speech or language impairment or both Of the children who continued to have persistent speech/language impairments at 5–6 years, 9 (75%) met diagnostic criteria for DCD.

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Table 1. (continued)

Authors, country, study design, recruitment	Participant characteristics	Outcome measurements compared	Results/Correlations
Gashaj et al. (2019), Germany, Cross-sectional, Kindergarten	N = 151 70M, 81F (46% boys) 5.6–7.3 years Normal	Motor (body coordination test for children, MABC-2) and learning (basic numerical skills)	Non-symbolic numerical skills were predicted by motor skills: FM skills predicted non-symbolic number line [f^2 = 0.062] and GM skills predicted non-symbolic magnitude [f^2 = 0.055]. Comparatively, symbolic numerical skills were not predicted by motor skills
Gieysztor et al. (2018), Poland, cross-sectional, preschool	N = 35 16M, 19F (46% boys) Age: 4–6 years Normal	Motor (MOT 4–6) and primitive reflexes (ATNR, STNR, TLR)	MOT 4–6 tasks significantly correlated with total primitive reflex score [$p < 0.05$; $r = -0.34$], such that higher motor efficiency statistically correlated with lower reflex scores
Hasanati et al. (2010), Iran, cross-sectional, Speech therapy clinics	N = 32 16M, 16F (50% boys) Age: 5 years Phonetic speech disorder: n = 16 Phonological speech disorder: n = 16	Motor (Oseretsky motor development scale)	Children in both speech disorder groups measured weak on motor skill assessment [p = 0.006] Mean total motor score in phonological speech disorder group was significantly lower than that of phonetic speech disorder group [1.79 ± 0.57 vs 2.29 ± 0.46], as were individual motor functions [balance movement skills, p = 0.004; bilateral motor coordination p = 0.001; and FM p = 0.04]
Iverson and Braddock (2011), USA, case-control, speech clinics/ preschools	N = 27 21M, 6F (78% boys) Age: 2.8–6.3 years Language impairment: n = 11 Control: n = 16	Motor (BDSI and CDI)	Children with language impairment consistently performed more poorly than TD group for both FM [BDSI (p = 0.001, Fisher's exact test), CDI (p = 0.0001] and GM [BDSI (p = 0.001, Fisher's exact test), CDI (p = 0.001)]

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Table 1. (continued)

Authors, country, study design, recruitment	Participant characteristics	Outcome measurements compared	Results/Correlations
Jascenoka et al. (2018), Germany, cross-sectional, daycare centers and centre for clinical psychology and rehabilitation	*N* = 57 46M, 41F (53% boys) Age: 3.0–6.8 years Normal	Participants were identified as having low, average or above-average motor skill using: Motor (LoMo 3–6) and cognitive (WPPSI-IV)	Children categorized as having "low" motor function on the LoMo 3–6 produced the lowest mean scores for all individual cognitive functions Statistically significant differences for specific cognitive functions were found between the "low" motor group and both the "average" [language comprehension (R^2 = 1.09, p = 0.001), visual-spatial processing (R^2 = 0.90, p = 0.009), processing speed (R^2 = 0.91, p = 0.018)], and "above average" [language comprehension (R^2 = 0.98, p = 0.029), visual-spatial processing (R^2 = 1.22, p = 0.001), processing speed (R^2 = 1.59, p < 0.001)] motor groups. No significant difference in cognitive scores were found between the "average" and "above average" groups
Kastner et al. (2011), Germany, cross-sectional, inpatient rehabilitation program	*N* = 52 (41 included in review) 21M, 20F (51% boys) Age 4.5–6.5 years Motor disorder: *n* = 21 Expressive language and motor disorders: *n* = 20	Cognitive (WPPSI-III)	The motor development disorder group performed below the normalized reference group for all subtests of WPPSI-III, with statistically significant findings for mosaic test (r = −0.62, p = 0.05), matrix reasoning (r = −0.58, p = 0.025), vocabulary test (r = −0.68, p = 0.037) and general knowledge (r = −0.70, p = 0.022) Mean scores for the language/motor disorder group were lower than those of the motor group for all WPPSI-III subtests The language/motor disorder group performed more than one standard deviation below the normalized refence group for all WPPSI-III subtests ($p \leq 0.003$)

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Table 1. (continued)

Authors, country, study design, recruitment	Participant characteristics	Outcome measurements compared	Results/Correlations
Kim et al. (2016), USA, Longitudinal, pre-kindergartens for children with disabilities	N = 2029 (1076 included in review) 1524M, 490F (75% boys) Age-T1: 3–5 years (beginning of pre-kindergarten) Age-T2: Not reported (end of pre-kindergarten) speech/language impairment (SLI): n = 192 SLD: n = 894	Motor (LAP-D) [T1] and cognitive (LAP-D: counting and matching) [T2]	FM skills significantly and positively predicted improvements in cognitive skills [$r = 0.53$, $p < 0.001$] for SLD group but NOT for the speech/Language impairment group GM skills did not significantly predict improvements in cognitive skills [$r = 0.33$, $p < 0.001$] for either speech/Language impairment or SLD groups
Livesey, et al. (2006), Australia, cross-sectional, private Kindergarten and public aftercare facilities	N = 36 15M, 21F (42% boys) Age: 5.25–6.9 years Normal	Motor (MABC) and cognitive (EF: DNS, SST)	EF moderately correlated to FM [SST ($r = -.356$, $p = 0.056$); DNS ($r = 0.420$, $p < 0.05$)] and to a lesser extent, ball skills [SST ($r = -.331$, $p = 0.056$)] but not balance FM skills [SST (Beta = −.339, $p = .077$), DNS (Beta = .322, $p = 0.017$)] and balls skills [SST, (Beta = −.396, $p = .064$)] were the strongest predictors of EF performance
Merriman and Barnett (1995), USA, cross-sectional, preschool programs for children with disabilities	N = 28 17M, 11F (61% boys) Age: 3.7–4.7 years Speech/language impaired	Motor (test of gross motor development) and speech/Language (revised preschool language scale)	GM skills were significantly related to auditory comprehension ($r = 0.41$, $p = 0.03$) and verbal ability ($r = 0.47$, $p = 0.01$). FM skills did not correlate significantly with language subscale A total of 18 (68%) and 1 (4%) child/children scored below the normative mean for age for GM and FM skills respectively

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Table 1. (continued)

Authors, country, study design, recruitment	Participant characteristics	Outcome measurements compared	Results/Correlations
Michel et al. (2018), Germany, Longitudinal case-control, regular and special needs preschools	N = 96 64M, 32F (67% boys) Age-T1: 4–6 years Motor impairment group: n = 48 Control n = 48 Age-T2: 5–7 years Motor impairment: Persisting: n = 25 Remission: n = 23 Control: n = 48	Motor (MABC-2) and cognitive (EF: Flanker, GoNogo, Color span backwards, Corsi-blocks backwards and HTKS)	Significant correlations, [$p < 0.05$], were found between motor coordination and EF in the persisting group, but not in the remission group. The persisting group showed weaker inhibition/interference control than working memory and switching
Michel et al. (2019), Germany, Longitudinal, Kindergartens	N = 173 99M, 74F (57% boys) Age-T1: 4–7 years Age-T2: 5–8 years Age-T3: 6–9 years Normal	Motor (MABC-2) [T1-3], Cognitive (EF: Flanker, GoNogo, Color span backwards, HTKS and Corsi-blocks backwards) [T1-3] and learning (WLLP-R: reading and WURT 1–2: Spelling) [T3 only]	Low to moderate correlations were found between motor coordination and both EF tasks and Scholastic achievement measures (reading and spelling) Motor coordination predicted reading and spelling skills at the end of first/second grade [$p < 0.05$]; however, additional modeling discovered this effect was due to EF.
Molitor et al. (2015), Germany, Longitudinal case-control, special needs kindergartens/preschools	N = 96 64M, 32F (67% boys) Age: 5–6 years Motor impaired: n = 48 Control: n = 48	Motor (MABC-2) and cognitive (EF: Flanker, GoNogo, Color span backwards, HTKS and Corsi-blocks Backwards)	The motor impairment group had lower scores for most EFs compared to controls. [GoNoGo, HTKS part 1, Flanker standard, color span backwards, corsi blocks backwards $F(1,92) = 4.2–7.5$, $p < 0.05$; Flanker mixed $F(1,92) = 3.2$, $p < 0.1$; HTKS part 3 $F(1,92) = 5.2$, $p < 0.5$] A subgroup within the motor impairment group was discovered, who did not show any EF impairments. Their manual dexterity scores were higher than the group with EF deficits

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Table 1. (continued)

Authors, country, study design, recruitment	Participant characteristics	Outcome measurements compared	Results/Correlations
Muursepp et al. (2011), Estonia, Case-control, Kindergartens	N = 54 100% boys Age: 5–6 years Expressive SLI: n = 28 Control: n = 26	Motor (MABC-2)	The expressive-SLI group performed considerably lower than controls for ball skills and balance [$p < 0.01$], impairment score and percentile [$p < 0.001$] There were no statistically significant differences [$p > 0.05$] between groups for manual dexterity
Muursepp et al. (2012), Estonia, Case-control, Kindergartens	N = 86 66M, 20F (77% boys) Age: 5–6 years Expressive SLI: n = 29 Articulation disorder: n = 27 Control: n = 30	Motor (MABC-2)	Children in expressive-SLI group performed considerably poorer than controls for motor skills [impairment score $p < 0.001$; percentile $p < 0.001$; manual dexterity $p < 0.05$; ball skills $p < 0.01$; and balance $p < 0.01$] The expressive-SLI group also performed significantly poorer than the articulation disorder group for motor skills [impairment score $p < 0.01$; percentile $p < 0.01$; and balance $p < 0.05$] No statistically significant differences for motor function were found between the articulation disorder group and controls [$p < 0.05$]
Pecuch et al. (2021), Poland, cross-sectional, preschools	N = 112 73M, 35F (65% boys) Age: 4.6–6.3 years Normal	Motor (MOT 4–6) and primitive reflexes (ATNR, STNR, TLR)	Children with increased reflex activity presented with lower motor efficiency ($r = -0.327$, $p < 0.05$) Correlations were found for motor efficiency and most individual reflexes (ATNR right = −0.204; STNR flexion $r = -0.201$; STNR extension $r = -0.317$; TLR flexion $r = -0.294$, $p < 0.05$)
Reeves (1998), USA, Cross-sectional, Public independent schools	N = 60 39M, 21F (65% boys) Age: 3–5.11 years Speech-language delayed	Motor (PDMS)	Balance (dynamic and static), locomotor tests, and receipt and propulsion were found to be difficult in both the 3-years and 4-years age groups

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Table 1. (continued)

Authors, country, study design, recruitment	Participant characteristics	Outcome measurements compared	Results/Correlations
Sack et al. (2021), USA, Longitudinal case-control, school and clinical programs	N = 29 15M, 14F (52% boys) Age-T1: 4–5 years Age-T2: 6–7 years DLD: n = 40 Normal: n = 21	Motor (MABC-2) [T1] and speech/Language (SPELT-P2, SPELT-3 SS, FVMC and BBTOP) [T1] (core language score SS from CELF-4) [T2]	Most MABC-2 scores in DLD preschool group correlated with language scores at 2-years follow-up: Total MABC-2 (r = 0.638, p = 0.025), balance (r = 0.614, p = 0.034) and manual dexterity (r = 0.670, p = 0.017). Aiming and catching was the exception (r = 0.321, p = 0.309) For the non-DLD preschool group, motor scores did not predict language outcome at 2 years follow-up
Simpson et al. (2019), England, Observational cohort, Preschools	N = 100 Experiment 2 only 55M, 45F (55% boys) Age: 3–4 years Normal	Motor (PDMS) and cognitive (EF: S-RC)	FM control and response inhibition were found to be substantially associated [t = 4.43, p < 0.001]. No association was found between GM control and response inhibition [t = 0.137, p = 0.891]
Son and Meisels (2006), USA, Longitudinal, ECLS-K survey	N = 12583 6342M, 6241F (50% boys) Age-T1: 4–6 years Age T-2: Not reported (average of 18.4 months after T1) Normal	Motor (ESI-R) [T1] and cognitive (reading and mathematics achievement) [T1 and T2]	A significant relationship was found between motor skills and later cognitive achievement, with visual-motor scores (including FM skills and draw a person test) more significantly correlated than GM scores [p < 0.001]. Such correlations were significantly higher for math score than reading [p < 0.01] Motor skills combined with kindergarten reading scores, significantly predicted spring first-grade reading achievement (R = 0.53)

(continued)

Table 1. (continued)

Authors, country, study design, recruitment	Participant characteristics	Outcome measurements compared	Results/Correlations
Wassenberg et al. (2005), Netherlands, Mixed methods, Case-control, Normal kindergarten	N = 378 213M, 165F (56% boys) Age: 5–6 years Externalizing: n = 145 Internalizing: n = 46 Control: n = 187	Motor (MMT) and cognitive (EF: K-ABC, ANT, Progressive figures test)	General cognitive performance was significantly related to all motor measures. However, after statistically controlling for attention, this general relationship did not reach significance Motor performance was found to have a positive correlation [$p < 0.05$, CI 95%] with several specific cognitive measures (working memory and verbal fluency), independent of attention [odds ratio > 1]

KEY: ANT(Amsterdam Neuropsychological Tasks), ATNR(Asymmetrical Tonic Neck Reflex), BBTOP(Bankson-Berthnal Test of Phonology), BDSI(Battelle Developmental Screening Inventory), CDI(Child Development Inventory), CELF-4(Clinical Evaluation of Language Fundamentals, 4th Edition), CELF-P-2(Clinical Evaluation of Language Fundamentals-Preschool-2), DCD(Developmental Coordination Disorder), DLD(Developmental Language Disorder), DNS(Day night stroop), DSLD(Developmental Speech and Language Disorders), EF(executive function), EOWPVT-R(Expressive One Word Picture Vocabulary Test-R), ESI-R(Early Screening Inventory-Revised), FM(fine motor), FVMC(Finite Verb Morphology Composite), GFTA-2(Goldman Fristoe Test of Articulation-2), GM(gross motor), HTKS(Head-Toes-Knees-Shoulders), K-ABC(Kaufman Assessment Battery for Children), LAAP(Language Ability Assessment for Preschoolers), LAP-D(Learning accomplishment profile-diagnostic), LoMo 3-6(Leistungsinventur zur objective Uberprufung der motorischen Fahigkeiten von 3-bis 6-Jahrigen), MABC(Movement Assessment Battery for Children), MABC-2(Movement Assessment Battery for Children-2), MMT(Maastricht Motor Test), MOT 4–6(Motor Proficiency Test for Children), PDMS(Peabody Developmental Motor Scales), PPVT-R(Peabody Picture Vocabulary Test-Revised), PPVT-III(Peabody Picture Vocabulary Test-Third Edition), SLD(Specific Learning Disorder), SLI(Specific Language Impairment), SPELT-P2(Structured Photographic Expressive Language Test-Preschool 2), SPELT-3 SS(Structured Photographic Expressive Language Test, 3rd Edition), S-RC(stimulus-response compatibility), SST(Stop-signal Task), STNR(Symmetrical Tonic Neck Reflex), TLR(Tonic Labyrinthine Reflex), WJIII(Woodcock-Johnson III), WLLP-R(Wurzburger Leise Leseprobe-Revision), WPPSI-III(Weschler Preschool and Primary Scale of Intelligence, 3rd Edition), WPPSI-IV(Weschler Preschool and Primary Scale of Intelligence, 4th Edition), WURT(Wurzburger Rechtschreibtest fur 1 und 2).

of sampling and measures taken to minimize non-response bias. All studies utilized valid and reliable measurement tools and other common strengths were direct data collection from participants at appropriate points in time.

Results by outcome

Significant heterogeneity in outcome measures and sample populations was discovered in this collection of papers, creating challenges in extrapolating correlations between these phenomena.

Motor function. Motor function was investigated in all 27 articles, including gross motor assessment in all except one study (Kastner et al., 2011) and fine motor assessment in all except two (De Waal, 2019; Kastner et al., 2011). Of the 13 standardized motor assessment batteries utilized in the collection, six were employed in multiple studies (Motor Assessment Battery for Children (MABC), MABC, 2nd Ed (MABC-2), Peabody Developmental Motor Scales (PDMS), Early Screening Inventory-Revised (ESI-R), Motor Proficiency Test for Children between four and six years (MOT 4–6), Bruininks-Oseretsky), with the MABC-2 and its predecessor, MABC equally dominant, represented in six studies each. Despite being frequently employed, MABC/MABC-2 scores were compared to different functions, thus complicating result comparisons, and preventing meta-analysis. Similarly, crossover of subtests between studies (e.g. human figure drawing and dynamic balance), were either not scored separately or were compared to different functions and therefore, comparison of results could not occur.

Cognition/learning function. All studies except two (Gieysztor et al., 2018; Pecuch et al., 2021) investigated a learning disorder or cognitive skill. Of the many areas of learning and cognition represented in this collection of studies, speech and language were predominant, incorporating prediagnosed sample populations in 11 studies (DiDonato Brumbach and Goffman, 2014; Gaines and Missiuna, 2006; Hasanati et al., 2010; Iverson and Braddock, 2011; Kastner et al., 2011; Kim et al., 2016; Merriman and Barnett, 1995; Muursepp et al., 2011; Muursepp et al., 2012; Reeves, 1998; Sack et al., 2021) and additional testing in another three studies (Cheng et al., 2009; De Waal, 2019; Jascenoka et al., 2018). Executive function was also well represented, being included in 14 tests across 10 studies (Asonitou et al., 2012; Cameron et al., 2012; Jascenoka et al., 2018; Kastner et al., 2011; Livesey et al., 2006; Michel et al., 2018; Michel et al., 2019; Molitor et al., 2015; Simpson et al., 2019; Wassenberg et al., 2005). Other cognitive/learning outcome measures included academic knowledge, such as mathematics ($n = 4$), reading ($n = 2$), and spelling ($n = 1$). Despite overlap of skills tested, significant variation in study design and sample populations made comparing results difficult.

Primitive reflexes. Three primitive reflexes were assessed between three studies (Callcott, 2012; Gieysztor et al., 2018; Pecuch et al., 2021): ATNR, Symmetrical Tonic Neck Reflex, and Tonic Labyrinthine Reflex. The ATNR was the only reflex represented in all three studies; however, testing positions and measurement scales differed.

A summary of results by test for all studies are included in Table 1.

Evidence for outcomes

Primitive reflexes, motor function, and learning outcome. Only one study meeting inclusion criteria assessed primitive reflexes, motor function and learning outcome (Callcott, 2012). The ATNR was a core focus of this study by Callcott (2012), who found ATNR severity to be positively correlated with manual dexterity ($R = 0.446$, $p = 0.004$) and significantly predictive of total motor function scores ($R = 0.417$, $p = 0.007$) in a sample of 40 indigenous children. No correlation, however, was observed between ATNR and specific gross motor skills, such as aiming and catching ($R = 0.201$, $p = 0.214$) or balance ($R = 0.261$, $p = 0.103$). Callcott (2012) further investigated school readiness in those children obtaining high ATNR scores of 6 on a 0–6 scale measured using the Schilder method. Qualitative analysis of human figure drawing and teacher interviews discovered high ATNR scores had a negative impact on school readiness (Table 1). Although all three phenomena were assessed in this study, motor and learning functions were not directly compared.

Two studies compared primitive reflexes and total motor function (MOT 4–6) in a cohort of healthy children (Gieysztor et al., 2018; Pecuch et al., 2021), with both finding higher motor efficiency correlated with lower reflex retention ($R = -0.34$, $p < 0.05$) (Gieysztor et al., 2018), ($R = -0.327$, $p < 0.05$) (Pecuch et al., 2021). Despite measuring three individual primitive reflexes, Gieysztor et al. (2018), provided only a total reflex score comparison to motor function. Comparatively, Pecuch et al. (2021) described most reflexes individually correlated with motor efficiency ($p < 0.05$). Although the MOT 4–6 measures four distinct motor areas, including fine and gross motor, only total motor scores were provided for both studies.

Motor and learning function

Motor function and speech/language. Of the 14 studies contrasting motor and speech/language function, 13 reported positive correlations between these measures, with a majority finding associations for both gross and fine motor skills. DCD was significantly related to developmental speech and language disorder (DSLD) (chi-square = 5.77, $p = 0.289$) in a study by Cheng et al. (2009), who found children with DCD were three times more likely to be diagnosed with DSLD than non-DCD children. Similarly, Gaines and Missiuna (2006), showed nine of the twelve (75%) children with persistent speech and language impairments met diagnostic criteria for DCD according to MABC scores.

Four case control studies (DiDonato Brumbach and Goffman, 2014; Iverson and Braddock, 2011; Muursepp et al., 2011; Sack et al., 2021) found consistently lower scores for language impairment groups compared to controls. DiDonato Brumbach and Goffman (2014) reported lower motor scores for the SLI group of children compared to the control group ($F(1,18) = 11.98$, $p = 0.003$) with similar results observed for fine and gross motor and an overt motor impairment (≥1 SD below mean on PDMS) discovered in five of the 11 (45%) children with SLI. Similarly, Iverson and Braddock (2011) observed children with language impairment consistently performed more poorly than the control children for both fine and gross motor function ($p = 0.001$, Fisher's Exact Test) on the Batelle Developmental Screening Inventory. Utilizing the MABC, Muursepp et al. (2011) reported considerably poorer gross motor skills in the expressive-SLI group compared to controls (ball skills and balance, $p < 0.01$; impairment score and percentile, $p < 0.001$); however, no differences were discovered between groups for fine motor ($p > 0.05$). Sack et al. (2021) observed most MABC-2 scores at preschool age correlated with language scores (Total $p = 0.025$, balance $p = 0.034$, manual dexterity $p = 0.017$) at 2-years follow-up for the developmental language disorder group but not controls.

Motor function of two different speech and language impairment groups were contrasted in two studies (Hasanati et al., 2010; Muursepp et al., 2012). Muursepp et al. (2012) found the articulation disorder group performed better than the expressive-SLI group on the MABC (impairment score/percentile $p < 0.001$, ball skills/balance $p < 0.01$, manual dexterity $p < 0.05$), and had comparable motor skills to the control group ($p < 0.05$). Likewise, Hasanati et al. (2010) reported both groups produced diminished scores on the Oseretsky motor development scale with weaker motor skills found in the phonological group compared to the phonetic group for both total motor score (1.79±0.57 vs 2.29±0.46, $p = 0.006$) and individual functions (balance $p < 0.004$; bilateral motor coordination $p = 0.001$; and fine motor $p = 0.04$).

Two cross-sectional studies (Merriman and Barnett, 1995; Reeves, 1998) established correlations between speech/language and gross motor skills. Reeves (1998) described dynamic and static balance, receipt and propulsion, and locomotor tests (PDMS) as difficult in 3- and 4-year-old children with speech-language delay. Likewise, Merriman and Barnett (1995) found that 18 (68%) children with speech/language impairment scored below the normative mean for age for gross motor skills, compared to 1 (4%) child for fine motor skills, using the Test of Gross Motor Development.

Relationships between motor and language scores were discovered in two cross-sectional studies (De Waal, 2019; Jascenoka et al., 2018) involving normal children. Most gross motor tasks from the Kinderkinetics Screening Assessment (KSA) were found to moderately correlate with home language ($R > 0.3$, $p \leq 0.05$) in the study by De Waal (2019). Language comprehension correlated with Total motor score of the Performance inventory for objective testing of motor skills in 3-to-6 year olds (LoMo 3–6) ($r = 0.24$, $p < 0.05$) in a study by Jascenoka et al. (2018).

Motor function and executive function. Positive relationships were identified between motor and executive function for all 10 studies comparing these factors, including five studies reporting fine motor correlations (Asonitou et al., 2012; Cameron et al., 2012; Livesey et al., 2006; Michel et al., 2019; Simpson et al., 2019). Livesey et al. (2006) discovered executive functions moderately correlated to fine motor skills (Stop-signal task (SST) $R = -0.356$; Day Night Stroop $R = 0.420$, $p < 0.05$)) and to a lesser extent, ball skills (SST $R = -0.331$, $p = 0.056$) on the MABC, in a cohort of normal preschool children. Simpson et al. (2019) observed fine motor ($t = 4.43$, $p < 0.001$) but not gross motor scores ($t = 0.137$, $p = 0.891$) correlated with response inhibition in a sample of normal children. Similarly, Cameron et al. (2012) reported total fine motor scores positively correlated with executive function (Head-toes-knees-shoulders (HTKS) $p < 0.01$) in a group of normal children. Asonitou et al. (2012) found manual dexterity significantly correlated with simultaneous cognitive processing in both DCD ($r = -.283$, $p < 0.05$) and control ($r = -0.322$, $p < 0.05$) groups, with poorer performance observed in the DCD group for all tasks. Michel et al. (2019) discovered low to moderate correlations between specific executive and motor functions in a sample of normal children with most significant associations observed for manual dexterity (Color span backwards and Corsi blocks backward $R = 0.21$, $p < 0.01$) and balance (Go/NoGo $R = 0.31$, $p < 0.01$ and Corsi blocks backwards $R = 0.25$, $p < 0.01$).

Multiple disorder groups were investigated in four studies (Kastner et al., 2011; Jascenoka et al., 2018; Michel et al., 2018; Wassenberg et al., 2005) with correlations between executive and motor functions found to vary between groups. Motor score (Maastricht Motor Test) correlated with individual executive functions, working memory, and verbal fluency ($p < 0.05$, CI 95%), for both behavior groups and controls independent of attention (odds ratio > 1) in a study by Wassenberg et al. (2005). Michel et al. (2018) reported significant correlations ($p < 0.05$) between total MABC-2 scores and specific executive functions (interference control (Flanker standard accuracy), switching (part 3 of HTKS task), working memory (corsi-blocks backwards)) in a group of children with persisting motor impairments, but not the remission group. A study by Jascenoka et al. (2018) found a group categorized as having “low” motor function on the LoMo 3-6, produced significantly lower scores for visual-spatial processing compared to both the ‘average’ (R^2 = 0.90, p = 0.009) and “above-average” motor groups (R^2 = 1.22, p = 0.001). Kastner et al. (2011) observed both the motor disorder and comorbid expressive-language/motor disorder groups performed below the norm referenced scores for executive functions, visual-spatial (motor $r = -0.62$, $p = 0.05$, comorbid $r = -1.51$, $p = 0.00$) and fluid reasoning (motor $r = -0.58$, $p = 0.025$, comorbid $r = -1.86$, $p = 0.01$), with the comorbid group performing one standard deviation below the mean ($p \leq 0.003$).

Molitor et al. (2015) found lower executive function scores for most tasks in the motor impairment group compared to controls (Go/NoGo, HTKS part 1, Flanker standard, Color span backwards, Corsi blocks backwards $F(1,92) = 4.2–7.5$, $p < 0.05$; Flanker mixed $F(1,92) = 3.2$, $p < 0.1$; HTKS part 3 $F(1,92) = 5.2$, $p < 0.5$). Additionally, Molitor et al. (2015) identified a motor impairment subgroup, who despite producing low total motor scores, presented with no executive function deficits and manual dexterity scores that exceeded those of the group with poor executive function ($F(1,45) = 4.12$, $p < 0.05$).

Motor function and cognitive achievement. Motor skills were found to be predictive of later cognitive achievement in four longitudinal studies (Cameron et al., 2012; Kim et al., 2016; Michel et al., 2019; Son and Meisels, 2006). Kim et al. (2016) utilized the Learning accomplishment profile-diagnostic to observe fine (R = 0.53, $p < 0.001$), but not gross motor (R = 0.33, $p < 0.001$) skills, significantly predict future cognitive skills in children with specific learning disorder (SLD). Fine motor skills were similarly shown to predict higher levels on Woodcock-Johnson III assessment, except applied problems (mathematics) in a study by Cameron et al. (2012). Although Michel et al. (2019) identified motor coordination in kindergarten as predictive of reading (Wurzburger Leise Leseprobe-Revision) and spelling (Wurzburger Rechtschreibtest 1–2) achievement at the end of first/second grade in a group of normal children ($p < 0.05$), this effect disappeared when executive function was added to modeling. Son and Meisels (2006) reported motor skills were significantly related to later reading and mathematics achievement, with fine motor scores more significantly correlated than gross motor scores (ESI-R) ($p < 0.001$), and mathematics more so than reading correlations ($p < 0.01$).

Two additional studies (De Waal, 2019; Gashaj et al., 2019a) observed relationships between varying motor functions and mathematics with De Waal (2019) finding the largest correlations between gross motor skills (KSA) and mathematics ($p \leq 0.05$), compared to Gashaj et al. (2019a) who found connections between motor function (MABC-2) and non-symbolic numerical skills (fine motor f^2 = 0.062; gross motor f^2 = 0.055), but not symbolic numerical skills.

Discussion

This systematic review reports that associations exist between learning disorders, motor function, and primitive reflexes in pre-school age children, with findings predominant between motor function and the learning areas of speech/language, executive function, and academic achievement. While only three papers included primitive reflexes and all observed relationships between motor function and primitive reflexes.

The reviewed literature suggests diminished fine and gross motor function may be observed in children with a variety of speech and language disorders. This is consistent with research involving older age groups (Visscher et al., 2007). Furthermore, motor function was found to vary between different speech/language groups. Two review papers (Hasanati et al., 2010; Muursepp et al., 2012) each tested two distinct speech and language disorder groups and discovered motor differences between groups. One study (Hasanati et al., 2010) reported significantly lower motor scores in a phonological speech disorder group compared to the phonetic disorder group and a second study (Muursepp et al., 2012) identified motor deficits in the SLI group but not the articulation group. This is compatible with earlier work which has shown the speech and language disorder type impacts motor performance differently (Visscher et al., 2007), suggesting that specific motor deficits may vary between disorders. The only review article to not find an association between speech/language and motor function (Kim et al., 2016) studied a group of children with speech/language delay. This sample did not undergo any formal speech or language testing, which may have provided insight into these study findings and if any potential subgroup existed that may conform to the remainder of the review collection findings.

The results of this review identified two main areas of cognitive measurement: executive function and academic knowledge/achievement. Optimum learning conditions to achieve academic success require the individual to possess foundational executive functions, including ability to pay attention (cognitive flexibility), recall instructions (working memory), and exhibit self-control (inhibitory control) (McClelland and Cameron, 2019). Positive correlations between motor function and both executive function and academic achievement were identified in this review, which is consistent with research in older populations (Gashaj et al., 2019b; Westendorp et al., 2011).

Although relationships were observed between executive function and total motor score (Michel et al., 2018; Wassenberg et al., 2005) and balance (Michel et al., 2019), fine motor skills were more frequently associated being represented in five of the 10 (50%) review studies investigating executive function. Whilst one review study (Cameron et al., 2012) reports correlations between fine motor and total executive function score (HTKS), other review studies described positive relationships with more specific executive functions, such as response inhibition (Livesey et al., 2006; Simpson et al., 2019), interference control (Livesey et al., 2006), simultaneous processing (Asonitou et al., 2012), and working memory (Michel et al., 2019). It has been suggested by Van der Fels et al. (2015) that fine motor skills place high demands on cognitive processes and hence are more closely related than gross motor skills.

One review study (Molitor et al., 2015) discovered a subgroup of children, who despite showing a deficit in total motor score, presented with comparatively normal fine motor and executive skills. This phenomenon may potentially be explained through the theory of automaticity, which describes how easier tasks become automated, producing a lower demand on executive functions (McClelland and Cameron, 2019). These varied findings between review studies may also suggest that similarly to the relationship between specific speech/language deficits and motor functions, particular executive functions interrelate with motor function differently.

Four longitudinal studies included in this review discovered motor function at preschool age to be predictive of future academic achievement. Motor scores correlated more significantly with mathematics than reading in one review article (Son and Meisels, 2006), with stronger correlations observed for visual-motor than gross motor scores. In this study, visuo-motor included both fine motor and draw-a-person test. This is consistent with other research that has observed fine motor skills strongly predict later achievement in mathematics and reading (Grissmer et al., 2010). Both fine motor and visual-motor skills are considered integral in the preschool period, underpinning foundation tasks involving literacy and mathematics (McClelland and Cameron, 2019). In contrast, another review study (Cameron et al., 2012) found those children with higher fine motor scores achieved higher academic knowledge scores, except in mathematics and additionally showed higher gross motor and draw-a-person scores in preschool predicted greater improvement at 1 year follow-up in academic knowledge, however at a marginally significant level. The authors of this review study acknowledged that shared variance between motor skill and executive function may have contributed to these findings. Such a relationship between motor and executive functions was specifically shown in a third review study, (Michel et al., 2019), which posited that when including executive function to statistical modeling, predictive significance of motor coordination on later reading and spelling achievement was removed. A fourth review study showed fine motor but not gross motor skills significantly and positively predicted improvements in cognitive skills (counting and matching) for a group of children with SLD (Kim et al., 2016). These findings are consistent with research in older age groups that have shown an association between SLD and fine motor skills (Baldi et al., 2016), and SLD and cognitive function (Ozkan et al., 2018).

Findings from our review also identified a significant correlation between high ATNR retention levels, poor fine motor skills and 'school readiness' in children that exhibited impulsivity, hyperactivity, and inattention (Callcott, 2012), characteristics indicative of ADHD. Much research supports a correlation between motor dysfunction and attention deficits (Brossard-Racine et al., 2011; Kadesjo and Gillberg, 1998; Kaplan et al., 1998) with about half of children with ADHD meeting criteria for DCD and vice versa (Kadesjo and Gillberg, 1998). Research in older children has shown ATNR retention to be predictive of academic achievement (Jordan-Black, 2005; McPhillips and Jordan-Black, 2006), motor score (DeGangi et al., 1980) and ADHD (Konicarova and Bob, 2013). Whilst the ATNR was one of three primitive reflexes measured by two review studies (Gieysztor et al., 2018; Pecuch et al., 2021), both papers limited reflex comparison to total motor scores, with Gieysztor et al. (2018) further limiting comparisons to total reflex score, preventing extrapolation of specific reflex retention relationships to specific motor functions. As each primitive reflex assesses unique aspects of sensory and motor function, it would be expected that motor skill would vary depending on the reflex retained (Zafeiriou, 2004). Discovery of similar ATNR predictive factors in preschool children would assist with early identification of and subsequent early intervention for motor deficits and disorders co-occurring with them.

This review reports fine motor skills as predictive of social skills in children with SLD (Kim et al., 2016). A large body of research supports linkage between fine motor performance and social skills (Bart et al., 2007; Piek et al., 2006) deducing that fine motor skills are not only essential for academic school activities, such as cutting, drawing and writing (Bart et al., 2007), but are fundamental for a child's inclusion in activities that lead to socializing with peers. Children with motor discoordination have been found to avoid situations in which their incompetence will be discovered. This leads to missed opportunities for further social and physical development and the resulting confidence and self-esteem that such interaction provides (Piek et al., 2006). As such, certain factors comorbid with motor deficits, such as social skills and mental health issues, would appear to be consequential to underlying developmental issues, and therefore potentially preventable if underlying motor deficits are addressed.

Many different co-occurring disorders have been documented in association with learning and motor difficulties, and in such significant numbers, that comorbidity is considered "the rule rather than the exception" (Kaplan et al., 1998). Indeed, several studies in this review also investigated comorbid factors, including behavior (Callcott, 2012; Wassenberg et al., 2005), social-skills (Muursepp et al., 2012) and self-concept (Michel et al., 2018, 2019), while other review studies investigating test groups excluded comorbid factors that may have provided further insight into underlying factorial relationships. For example, one review study (Hasanati et al., 2010) compared motor function between two speech disorder groups, yet excluded sensory motor problems and two studies (Muursepp et al., 2011, 2012) focusing on expressive-SLI, subsequently excluded participants with other speech/language deficits. By comparison, another review study (Reeves, 1998) recruited all speech and language deficits and then categorized participants accordingly. Given that speech and language deficits occur more frequently together than singularly (Eadie et al., 2014), this recruitment approach utilized by Reeves (1998) has potential to provide more in-depth comparisons between individual deficits. One speech/language delayed, motor impaired participant was excluded from another review study based on low intelligence scores (Gaines and Missiuna, 2006), which although a common reason for exclusion, is questionable, given that it has been shown that language ability does not differ significantly for intelligence scores (Fey et al., 1994).

Although research studies often exclude comorbidity, such recruitment limitations impact research outcome relatability into clinical practice and educational settings where comorbidity is the reality (Valtonen et al., 2004). With such high rates of comorbidity found between disorders, such as ADHD and DCD (Cairney et al., 2010), and SLI and DCD (Bishop, 2002), it has been postulated that children with such disorders experience a broader syndrome, with each disorder representing a single symptomatologic domain (Cairney et al., 2010; Hill, 2001). The concept of a broader syndrome is not new, with several theories described since the 1960s (Ingram, 1973; Kaplan et al., 1998; Visser, 2003). While none of these theories have succeeded to discover a common underlying mechanism (Visser, 2003), none have engaged with primitive reflexes. Primitive reflex retention has potential to explain the association between motor and cognitive function. While no one reflex can provide adequate explanation of such a complex relationship, primitive reflexes could provide a neurological framework on which to build understanding of relationships between specific motor and cognitive functions and accompanying comorbid factors.

Strengths and limitations

This is the first review to study primitive reflexes in preschool children. Strengths of this review include alignment with PRISMA, wide search of multiple databases with no date or language restrictions, vigorous systematic search methodology, a low-moderate risk of bias rating, and substantial agreement between authors regarding full text screening and risk of bias analysis.

Study limitations include a low number of total articles that include all three search hedges, including only three studies assessing primitive reflexes. Due to significant variation in study designs and non-congruent assessment tools, any comparison between studies must be analyzed with caution.

Implications for future research

Limited representation of primitive reflexes within the scientific literature, regarding both study inclusion and individual testing, is indicative that further research into primitive reflexes in this demographic is required. Given the developmental relationship between primitive reflex integration, and gross and fine motor function, more research into the association of these phenomena in the pre-school age group and their relationship with learning disorder development is also required. Such research should include: sample sizes of populations sufficient to infer statistical power for sub-analysis; comorbid factors to improve relatability of findings to the wider population; and clear descriptions of reported outcomes to ensure future reviews can more accurately compare data on this topic.

Implications for practice

The results of this review may improve understanding of the complexity of developmental disorders and comorbidity by health professionals. These findings suggest that motor screening at preschool age may be indicated on presentation of speech/language and/or executive function deficits.

Whilst the results of this review do no provide consistent evidence to directly inform practice regarding primitive reflex associations, as research evidence becomes more robust, the potential importance of this association may provide significant implications for childhood development.

Conclusion

Identifying learning disorders prior to school age would allow for early intervention implementation and potential prevention of learning deficits and various resulting negative impacts upon the child. Public health and education systems would also benefit from earlier diagnosis, given the financial impact learning disorders create. Neurological assessment of preschool children, with regards to motor skill and primitive reflex retention, may inform such early identification of learning disorders. This review highlights that limited studies have investigated the association between primitive reflexes, motor function and learning disorders in the pre-school age group. Positive associations were found between learning disorders and motor function with speech/language and executive function predominant. Comparatively, primitive reflexes have received little researcher attention. While correlations between phenomena have been found in this review, results must be interpreted with caution and future research into the associations between these three phenomena is required to help understand common underlying mechanisms that may inform earlier learning disorder identification.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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Supplemental Material

Supplemental material for this article is available online.

References

Adamovic T, Kosanovic R, Madic D, et al. (2014) Correlation between balance ability and speech-language development in children. *Collegium Antropologicum [Coll Antropol]* 39: 11–20.

Asonitou K, Koutsouki D, Kourtessis T, et al. (2012) Motor and cognitive performance differences between children with and without developmental coordination disorder (DCD). *Research in Developmental Disabilities* 33: 996–1005.

AUSPELD (2019) *Understanding Learning Difficulties: A Guide for Parents*. Western Australia: DSF Literacy Services.

Baldi S, Caravale B and Presaghi F (2016) Daily motor characteristics in children with developmental co-ordination disorder and in children with specific learning disorder. *Dyslexia* 24: 380–390.

Bart O, Hajami D and Bar-Haim Y (2007) Predicting school adjustment from motor abilities in kindergarten. *Infant and Child Development* 16(6): 597–615.

Bishop DVM (2002) Motor immaturity and specific speech and language impairment: evidence for a common genetic basis. *American Journal of Medical Genetics* 114: 56–63.

Brossard-Racine M, Majnemer A and Shevell MI (2011) Exploring the neural mechanisms that underlie motor difficulties in children with attention deficit hyperactivity disorder. *Developmental Neurorehabilitation* 14(2): 101–111.

Bundy AC, Naughton G, Tranter P, et al. (2011) The sydney playground project: popping the bubblewrap - unleashing the power of play: a cluster randomized control trial of a primary school playground-based intervention aiming to increase children's physical activity and social skills. *BMC Public Health* 11: 680.

Cairney J, Veldhuizen S and Szatmari P (2010) Motor coordination and emotional-behavioral problems in children. *Current Opinion in Psychiatry* 23: 324–329.

Callcott D (2012) Retained primary reflexes in pre-primary-aged Indigenous children: the effect on movement ability and school readiness. *Australasian Journal of Early Childhood* 37(2): 132–140.

Cameron CE, Brock LL, Murrah WM, et al. (2012) Fine motor skills and executive function both contribute to kindergarten achievement. *Child Development* 83: 1229–1244.

Cheng H-C, Chen H-Y, Tsai C-L, et al. (2009) Comorbidity of motor and language impairments in preschool children of Taiwan. *Research in Developmental Disabilities* 30(5): 1054–1061.

de Waal E (2019) Fundamental movement skills and academic performance of 5 to 6-year-old preschoolers. *Early Childhood Education Journal* 47: 455–464.

DeGangi GA, Berk RA and Larsen LA (1980) The measurement of vestibular-based functions in pre-school children. *The American Journal of Occupational Therapy* 34: 452–459.

DiDonato Brumbach AC and Goffman L (2014) Interaction of language processing and motor skill in children with specific language impairment. *Journal of Speech, Language, and Hearing Research* 57: 158–171.

Eadie P, Morgan A, Ukoumunne OC, et al. (2014) Speech sound disorder at 4 years: prevalence, comorbidities, and predictors in a community cohort of children. *Developmental Medicine and Child Neurology* 57: 578–584.

Earls M and Hay S (2006) Setting the stage for success: implementation of developmental and behavioral screening and surveillance in primary care practice-the North Carolina assuring better child health and development (ABCD) project. *Pediatrics* 118: 183–188.

Elkins J (2002) Learning difficulties/disabilities in literacy. *Australian Journal of Language and Literacy* 25: 11–18.

Fey ME, Long SH and Cleave PL (1994) Reconsideration of IQ criteria in the definition of specific language impairment. In: Watkins RV and Rice ML (eds) *Specific Language Impairments in Children*. Baltimore, MD: Brookes, 161–178.

Fletcher JM, Lyon GR, Fuchs L, et al. (2006) *Learning Disabilities: From Identification to Intervention*. New York: Guildford Press.

Freides D, Barbati J, van Kampen-Horowitz LJ, et al. (1980) Blind evaluation of body reflexes and motor skills in learning disability. *Journal of Autism and Developmental Disorders* 10(2): 159–171.

Gaines R and Missiuna C (2006) Early identification: are speech/language-impaired toddlers at increased risk for developmental coordination disorder? *Child: Care, Health and Development* 33(3): 325–332.

Gallahue D and Ozmun J (2006) *Understanding Motor Development: Infants, Children, Adolescents, Adults*. 6th ed. New York: McGraw-Hill.

Gashaj V, Oberer N, Mast FW, et al. (2019a) Individual differences in basic numerical skills: the role of executive functions and motor skils. *Journal of Experimental Child Psychology* 18: 187–195.

Gashaj V, Oberer N, Mast FW, et al. (2019b) The relation between executive functions, fine motor skills, and basic numerical skills and their relevance for later mathematics achievement. *Early Education and Development* 30: 913–926.

Gieysztor EZ, Choinska AM and Paprocka-Borowicz M (2018) Persistence of primitive reflexes and associated motor problems in healthy preschool children. *Archives of Medical Science* 14(1): 167–173.

Grissmer D, Grimm KJ, Aiyer SM, et al. (2010) Fine motor skills and early comprehension of the world: two new school readiness indicators. *Developmental Psychology* 46: 1008–1017.

Hasanati F, Khatoonabadi AR and Abdolvahab M (2010) A comparative study on motor skills in 5-year-old children with phonological and phonetic disorders. *Audiology* 19: 71–77.

Hill EL (2001) Non-specific nature of specific language impairment: a review of the literature with regard to concomitant motor impairments. *International Journal of Language & Communication Disorders* 36(2): 149–171.

Hoy D, Brooks P, Woolf A, et al. (2012) Assessing risk of bias in prevalence studies: modification of an existing tool and evidence of interrater agreement. *Journal of CLinical Epidemiology* 65: 934–939.

Ingram TTS (1973) Soft Signs. *Developmental Medicine and Child Neurology* 15: 527–530.

Iverson JM and Braddock BA (2011) Gesture and motor skill in relation to language in children with language impairment. *Journal of Speech, Language, and Hearing Research* 54(1): 72–86.

Jascenoka J, Walter F, Petermann F, et al. (2018) Zum Zusammenhang von motorischer und kognitiver Entwicklung im Vorschulalter. *Kindheit und Entwicklung* 27: 142–152.

Jordan-Black J-A (2005) The effects of the primary movement programme on the academic performance of children attending ordinary primary school. *Journal of Research in Special Educational Needs* 5(3): 101–111.

Kadesjo B and Gillberg C (1998) Attention deficits and clumsiness in Swedish 7-year-old children. *Developmental Medicine and Child Neurology* 40: 796–804.

Kaplan BL, Wilson BN, Dewey D, et al. (1998) DCD may not be a discrete disorder. *Human Movement Science* 17: 471–490.

Kastner J, Lipsius M, Hecking M, et al. (2011) Kognitive Leistungsprofile motorisch- und sprachentwicklungsverzogerter Vorschulkinder. *Kindheit und Entwicklung* 20: 173–185.

Kim H, Carlson AG, Curby TW, et al. (2016) Relations among motor, social, and cognitive skills in prekindergarten children with developmental disabilities. *Research in Developmental Disabilities* 53–54: 43–60.

Kiuru N, Poikkeus A-M, Lerkkanen M-K, et al. (2012) Teacher-perceived supportive classroom climate protects against detrimental impact of reading disability risk on peer rejection. *Learning and Instruction* 22: 331–339.

Konicarova J and Bob P (2013) Asymmetric tonic neck reflex and symptoms of attention deficit and hyperactivity disorder in children. *International Journal of Neuroscience* 123(11): 766–769.

Livesey D, Keen J, Rouse J, et al. (2006) The relationship between measures of executive funciton, motor performance and externalizing behaviour in 5- and 6-year old children. *Human Movement Science* 25: 50–64.

McClelland MM and Cameron CE (2019) Developing together: the role of executive function and motor skills in children's early academic lives. *Early Childhood Research Quarterly* 46: 142–151.

McPhillips M and Jordan-Black J-A (2006) Primary reflex persistence in children with reading difficulties (dyslexia): a cross-sectional study. *Neuropsychologia* 45(4): 748–754.

McWhirter K, Steel A and Adams J (2021) *The Association Between Learning Disorders, Motor Function and Primitive Reflexes in Preschool Children: Protocol for a Systematic Review [CRD42021265793].*

Merriman WJ and Barnett BE (1995) A preliminary investigation of the relationship between language and gross motor skills in preschool children. *Perceptual and Motor Skills* 81: 1211–1216.

Michel E, Molitor S, Schneider W, et al. (2018) Differential changes in the development of motor coordination and executive functions in children with motor coordination impairments. *Child Neuropsychology* 24: 20–45.

Michel E, Molitor S, Schneider W, et al. (2019) Motor coordination and executive functions as early predictors of reading and spelling acquisition. *Developmental Neuropsychology* 44: 282–295.
Molitor S, Michel E, Schneider W, et al. (2015) Exekutive Funktionen bei Kindern mit motorischen Auffalligkeiten [Executive functions in children with motor coordination impairments. *Kindheit und Entwicklung* 24: 181–188.
Moll K, Kunze S, Neuhoff N, et al. (2014) Specific learning disorder: prevalence and gender differences. *Plos One* 9(7): e103537.
Muursepp I, Aibast H, Gapeyeva H, et al. (2012) Motor skills, haptic perception and social abilities in children with mild speech disorders. *Brain and Development* 34(2): 128.
Muursepp I, Aibast H, Paasuke M, et al. (2011) Motor performance and haptic perception in preschool boys with specific impairment of expressive language. *Acta Paediatrica* 100: 1038–1042.
Niklasson M, Norlander T, Niklasson I, et al. (2017) Catching-up: children with developmental coordination disorder compared to healthy children before and after sensorimotor therapy. *Plos One* 12(10): e0186126.
Niklasson M, Rasmussen P, Niklasson I, et al. (2015) Adults with sensorimotor disorders: enhanced physiological and psychological development following specific sensorimotor training. *Frontiers in Psychology* 6: 480.
Ozkan S, Kara K, Almbaideen M, et al. (2018) Investigation of distinctive characteristics of children with specific learning disorder and borderline intellectual functioning. *Archives of Clinical Psychiatry* 45: 1–6.
Page MJ, McKenzie JE, Bossuyt PM, et al. (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *British Medical Journal* 372: n71.
Pecuch A, Gieysztor EZ, Wolanska E, et al. (2021) Primitive reflex activity in relation to motor skills in healthy preschool children. *Brain Sciences* 11(8): 967.
Piek JP, Baynam GB and Barrett NC (2006) The relationship between fine and gross motor ability, self-perceptions and self-worth in children and adolescents. *Human Movement Science* 25: 65–75.
Reeves L (1998) Gross and fine motor skill ability in preschool children with speech-language delays. *Clinical Kinesiology* 52: 28–34.
Sack L, Dollaghan C and Goffman L (2021) Contributions of early motor deficits in predicting language outcomes among preschoolers with developmental language disorder. *International Journal of Speech-Language Pathology* ,DOI: 10.1080/17549507.2021.1998629.
Scanlon D (2013) Specific learning disability and its newest definition: which is comprehensive? and which is insufficient? *Journal of Learning Disabilities* 46: 26–33.
Simpson A, Al Ruwaili R, Leonard H, et al. (2019) Fine motor control underlies the association between response inhibition and drawing skill in early development. *Child Development* 90: 911–923.
Son S-H and Meisels SJ (2006) The relationship of young children's motor skills to later school achievement. *Merrill-Palmer Quarterly* 52(4): 755–778.
Strooband KFB, de Rosnay M, Okely AD, et al. (2020) Systematic review and meta-analyses: motor skill interventions to improve fine motor development in children aged birth to 6 years. *Journal of Developmental and Behavioral Pediatrics* 41(4): 319–331.
Sugden DA, Kirby A and Dunford C (2008) Issues surrounding children with developmental coordination disorder. *International Journal of Disability, Development and Education* 55: 173–187.
Valtonen R, Ahonen T, Lyytinen P, et al. (2004) Co-occurrence of developmental delays in a screening study of 4-year-old Finnish children. *Developmental Medicine and Child Neurology* 46: 436–443.
van der Fels IMJ, te Wierike SCM, Hartman E, et al. (2015) The relationship between motor skills and cognitive skills in 4-16 year old typically developing children: a systematic review. *Journal of Science and Medicine in Sport* 18: 697–703.
Visscher C, Houwen S, Scherder EJA, et al. (2007) Motor profile of children with developmental speech and language disorders. *Pediatrics* 120(1): 158–163.
Visser J (2003) Development coordination disorder: a review of research on substypes and comorbidities. *Human Movement Science* 22: 479–493.

Wassenberg R, Feron FJM, Kessels AGH, et al. (2005) Relation between cognitive and motor performance in 5- to 6-year-old children: results from a large-scale cross-sectional study. *Child Development* 76(5): 1092–1103.

Westendorp M, Hartman E, Houwen S, et al. (2011) The relationship between gross motor skills and academic achievement in children with learning disabilities. *Research in Developmental Disabilities* 32(6): 2773–2779.

Willcutt EG, Boada R, Riddle MW, et al. (2011) Colorado learning difficulties questionnaire: validation of a parent-report screening measure. *Psychological Assessment* 23: 778–791.

Zafeiriou DI (2004) Primitive reflexes and postural reactions in the neurodevelopmental examination. *Pediatric Neurology* 31(1): 1–8.

Zelazny SM (1998) Does supine vs prone positioning affect acquisition of prone propping in 4-month-old infants? ProQuest Dissertations and Theses.