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Motor skills and internalizing problems throughout development: An integrative research review and update of the environmental stress hypothesis research

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ABSTRACT

Background: The Environmental Stress Hypothesis provides a conceptual framework detailing the complex relationship between poor motor skills and internalizing problems.
Aims: This integrative research aimed to synthesize studies that have evaluated complex pathways posited in the framework.
Method: This study followed the four stages of an integrative research review: (i) problem formation and research aims, (ii) literature search and data collection, (iii) data evaluation and analysis, and (iv) results and discussion.
Outcomes and Results: Twelve peer-reviewed, English language studies published within 2010–2018 were identified. These used mostly cross-sectional, correlational methods and provided varying levels of support for relationships posited in the framework in samples spanning early childhood to adulthood. Compared to intrapersonal factors (e.g., self-esteem/ perceived competence), interpersonal factors (e.g., social support, peer problems) were found to more strongly and consistently mediate the relationship between motor skills and internalizing problems.
Conclusions and Implications: There is growing empirical support for many of the Environmental Stress Hypothesis pathways. However, research to date is limited in the ability to establish causal relationships between variables, which is integral to the Environmental Stress Hypothesis. Intervention studies provide a useful type of experimental research that could establish causality between variables, while working to improve the physical and psychosocial functioning of people with poor motor skills.

What this paper adds

This study presents an integrative research review of twelve articles that have tested various complex relationships between motor skills and internalizing problems that are posited in the Environmental Stress Hypothesis. This framework consists of multiple mediating and moderating associations; no single study has evaluated the entire framework. Rather, studies evaluate select pathways embedded in this broader model. The current study unified these various evaluations into a single review in order to achieve a comprehensive understanding of the Environmental Stress Hypothesis.

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Through a literature search of multiple databases, a final sample of 12 articles were included in the current paper. These studies evaluated either the mediating and/or moderating pathways through which motor skills are posited to be associated with internalizing problems. The current findings indicated that the current body of evidence comprises of mostly correlational, cross-sectional research designs identifying a small-to-moderate negative association between motor skills and internalizing problems in community populations. These studies provide support for certain pathways, with consistent evidence of interpersonal factors (e.g., peer problems or perceived social support), though mixed findings were identified for other mediating variables (e.g., self-competence). While this limits the ability to make causal conclusions, these findings highlight potential targets for experimental and longitudinal studies, including intervention efforts that aim to improve both motor skills and psychosocial functioning. The current studies that have evaluated the Environmental Stress Hypothesis do not provide a complete account of the various pathways in the framework, indicating that ongoing evaluation is recommended.

1. Introduction

The ability to perform accurate and coordinated movements is integral to psychological and social development. Starting in early childhood, meeting developmentally appropriate movement milestones (i.e., crawling, walking) facilitates opportunities for enhanced psychosocial development (Piek, Baynam, & Barrett, 2006; Piek, Barrett, Smith, Rigoli, & Gasson, 2010; Poole et al., 2015a). For example, possessing the motor skills necessary to participate in structured and unstructured play with peers enables young children to refine their social skills, develop peer relationships and a sense of self-competence. Motor skills are also a precursor for cognitive and academic development; certain motor skills (i.e., handwriting) are fundamental in conventional school environments (Alloway, 2007). Even in the absence of a severe movement disorder (e.g., cerebral palsy, spina bifida), individuals who lack the necessary age-appropriate motor skills required to meet environmental demands encounter greater difficulties relative to their typically developing peers (Lingam et al., 2012; Skinner & Piek, 2001).

An association between motor development and psychosocial development has been hypothesized in research as early as the 1930s (Schilder, 1939), yet the substantial investigation of this relationship only started after the Diagnostic and Statistical Manual of Mental Disorders (DSM)–Third Edition, Revised (American Psychiatric Association [APA], 1987) formally recognized developmental coordination disorder (DCD) as a clinically diagnosed impairment. In the current fifth edition of the DSM, a diagnosis of DCD may be warranted when the following criteria are met: (a) the individual's motor skills are substantially below their age and opportunity for skill acquisition, (b) these movement difficulties interfere with activities of daily living, academic performance, leisure and play, (c) the onset of these symptoms occur in the early developmental period and (d) these symptoms must not be better explained by other conditions (American Psychiatric Association [APA], 2013, p74). DCD is thought to affect approximately 5%–6% of children (APA, 2013). The DSM-5 also recognizes the potential persistence of the disorder into adolescence and adulthood.

The absence of a 'gold standard' diagnostic assessment for DCD has led to the adoption of numerous operational definitions of DCD within the literature (Chen, Tseng, Hu, & Cermak, 2009; Venetsanou et al., 2011). Some studies use the full DSM diagnostic criteria to identify the disorder; others focus solely on the first criterion. This has led to the development of several alternative terms ('at-risk for DCD', 'probable DCD', 'motor coordination problems', 'movement difficulties' or 'clumsy'). Irrespective of which chosen term is adopted, each of these studies describes a population who possess poor motor skills relative to their typically developing peers. For the purposes of this paper, we will use the term 'poor motor skills' as an umbrella term that encapsulates these populations; the term DCD will only be used when studies have explicitly used this term.

The literature is replete with studies documenting various psychosocial difficulties experienced by children with poor motor skills. Children with poor motor skills have been found to be more introverted, report poorer physical and social self-competence and be more anxious compared to their typically functioning peers (Schoemaker & Kalverboer, 1994). Skinner and Piek (2001) found children and adolescents diagnosed with DCD reported poor self-competence, less social support and higher levels of anxiety, compared to their non-DCD peers. Furthermore, the adolescents with DCD reported more severe symptoms than their child counterparts, suggesting that the unattended psychosocial consequences of poor motor skills may persist, or even worsen over time (Skinner & Piek, 2001). This has since been supported by several longitudinal and cross-sectional studies which have established a link between childhood motor skills and psychosocial functioning in later life (Lingam et al., 2012; Piek et al., 2010; Poole et al., 2015a; Rigoli et al., 2017)

Recent studies have identified children with poor motor skills to be at greater risk of interpersonal difficulties. For example, children with DCD tend to have fewer friends and positive peer interactions, lower perceived social support, poorer social skills, greater social isolation and a greater chance to be rejected or bullied by peers (Campbell, Missiuna, & Vaillancourt, 2012; Poulsen, Ziviani, Johnson, & Cuskelly, 2008; Wagner, Bös, Jascenoka, Jekauc, & Petermann, 2012). These difficulties often begin in early childhood, but the consequences are rarely noticed by parents until later childhood (Kim, Carlson, Curby, & Winsler, 2016; King-Dowling, Missiuna, Rodriguez, Greenway, & Cairney, 2015; Missiuna, Moll, King, King, & Law, 2007). The consequences of poor motor skills during childhood can persist into later life, regardless of whether there is an improvement in motor proficiency (Lingam et al., 2012; Poole et al., 2016).

Poor motor skills are also associated with poor self-perceptions. Children with poor motor skills may unsurprisingly perceive themselves to be less physically competent than their typically developing peers; however, they also report lower self-esteem and global self-worth, and being less physically attractive, socially competent, and academically competent (Engel-Yeger & Hanna Kasis, 2010; Losse et al., 1991; McIntyre, Chivers, Larkin, Rose, & Hands, 2015). These findings suggest that the consequences of poor motor skills may extend into domains of psychosocial functioning unrelated to motor proficiency. These factors are also problematic and may lead to difficulties in later life (Missiuna, Moll, King, Stewart, & Macdonald, 2008; Rigoli et al., 2017).

Though motor skills have been shown to be associated with a range of psychosocial outcomes, emphasis has been directed towards the elevated levels of internalizing problems (i.e., symptoms of depression and anxiety) that are commonly observed in children with poor motor skills (Cairney, Rigoli, & Piek, 2013; Wagner, Jekauc, Worth, & Woll, 2016). An individual may experience internalizing problems without meeting diagnostic criteria for a disorder. However, even in the absence of clinically significant levels of anxiety and/or depression, these symptoms can still be distressing enough to adversely impact overall functioning and quality of life, particularly if these elevated symptoms are sustained (Cairney et al., 2013). Numerous studies have shown that children with DCD also report higher levels of both anxious and depressive symptoms when compared to their non-DCD counterparts (Francis & Piek, 2003; Lingam et al., 2012; Missiuna et al., 2014; Piek et al., 2007; Sigurdsson, Van Os, & Fombonne, 2002; Skinner & Piek, 2001). This finding has also been replicated in cross-sectional and longitudinal studies on adolescent and adult samples, suggesting a potentially life-long impact (Harrowell, Hollén, Lingam, & Emond, 2017; Hill, Brown, & Sorgardt, 2011).

Despite many studies that have found those with poor motor skills often experience greater internalizing problems, our understanding of why this is the case remains comparatively undeveloped (Cairney et al., 2013). While there is some suggestion that motor coordination and emotional regulation have shared biological causes, biological factors alone are unable to completely explain this association (Nicolson, Fawcett, & Dean, 2001). Piek et al. (2007) utilized a monozygotic differences design and compared the depressive symptomatology between twins discordant for DCD. The authors identified that the twins with DCD reported significantly higher depressive symptoms compared to their non-DCD twin, which was attributed to unique environmental experiences (Piek et al., 2007). Another twin/sibling study by Waszczuk, Leonard, Hill, Rowe, and Gregory (2016) found that unique environmental experiences, (e.g. the numerous interpersonal and intrapersonal factors mentioned previously) accounted for approximately one-third of the variance in the etiology of coordination difficulties and internalizing symptoms. These findings suggest that while poor motor skills and internalizing problems may share some genetic/environmental causes, the presence of poor motor skills may itself be a cause of internalizing problems (Cairney & Veldhuizen, 2013; Cairney, Veldhuizen, & Szatmari, 2010).

1.1. The environmental stress hypothesis

Cairney et al. (2010) conceptualized the Environmental Stress Hypothesis as a theoretical framework that details how poor motor skills (originally operationalized as DCD in childhood) contribute to greater internalizing problems. In brief, poor motor skills are posited to be a source of primary stress that gives rise to numerous psychosocial consequences (mentioned previously) that are a source of 'secondary stress'. Though comprised of numerous direct relationships between variables, a fundamental underpinning of this framework are the numerous indirect pathways through which poor motor skills are posited to cause internalizing problems; poor motor skills are posited as an indirect cause of internalizing problems via these secondary stressors. The framework was recently elaborated in 2013 to include physical inactivity and obesity as additional secondary stressors (Cairney et al., 2013). This is visually presented in Fig. 1.

The Environmental Stress Hypothesis has provided a foundation for studies aiming to investigate the relationships between motor

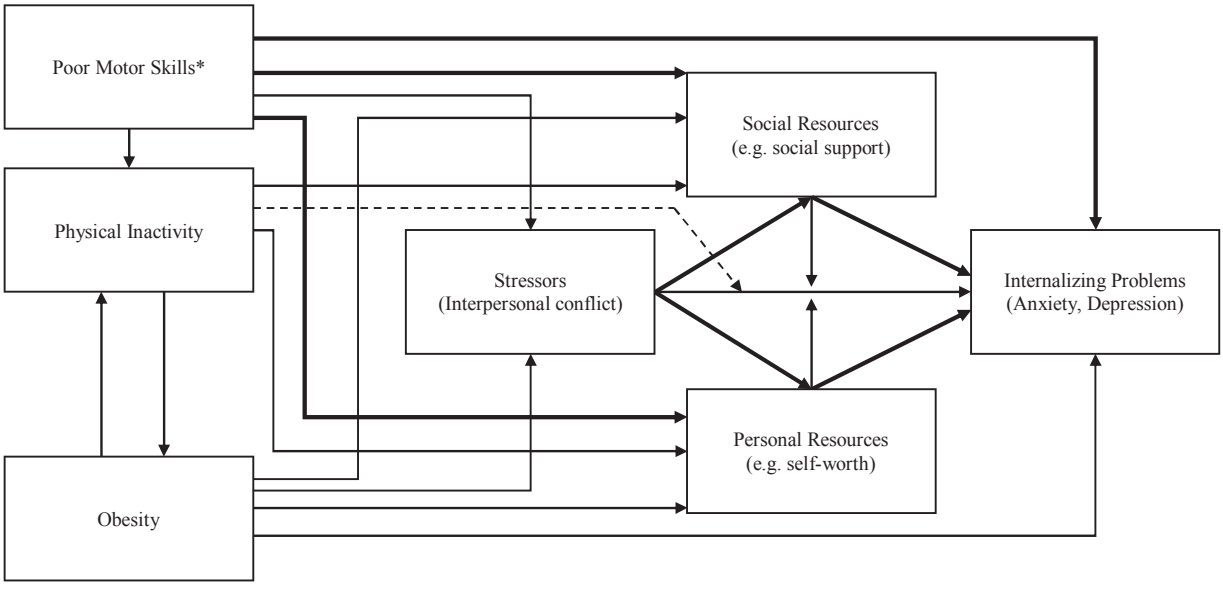

Fig. 1. Visual representation of the Environmental Stress Hypothesis as it is described in Cairney et al. (2010) and visually presented Cairney et al. (2013), p. 233), adapted for the current study. Physical inactivity and obesity (and the adjoining pathways) were introduced in the Cairney et al. (2010) revision of the framework. Pathways depicted in bold are refer to the key pathways that were tested in the included articles.
*Poor Motor Skills was originally operationalized as DCD in childhood, though this has been revised based on the literature reviewed in the current study.

skills, physical and psychosocial factors, and internalizing problems. As the framework is comprised of many direct and indirect relationships between variables, studies often evaluate a subset of relationships embedded within the overarching framework. The framework has also been adapted to include variables not originally hypothesized in the framework. This has led to the framework being used to investigate outcomes beyond internalizing problems, such as externalizing problems and pro-social behavior (Piek et al., 2015; Wagner et al., 2016). Direct relationships between variables are comparatively more established empirically compared to the more complex indirect relationships between multiple variables in the framework. An emerging body of research in this area has started to empirically evaluate such relationships, as these are fundamental to the Environmental Stress Hypothesis. To date, evidence supporting the framework comes from a combination of cross-sectional, longitudinal and experimental research spanning samples in early childhood to adulthood (Mancini, Rigoli, Cairney et al., 2016; Mancini, Rigoli, Heritage et al., 2016).

1.2. The integrative research review

The overarching goal of an integrative research review is to infer generalizations about a subject through the process of analyzing and summarizing studies on the same issue (Cooper, 1998; Russell, 2005). A rigorous integrative research review also allows researchers to link related areas, evaluate the strengths and limitations of the evidence, and generate new research questions or frameworks and direct future research in the area (Russell, 2005).

There are several key reasons why an integrative research review of the Environmental Stress Hypothesis is important. First, the framework is too complex to be adequately tested in a single study; each of the current studies in this area instead tests subsections of the broader framework. Second, the relationships between motor skills and psychosocial well-being are not confined to a homogenous population of children with DCD. Rather, these relationships have been identified to exist across the full continuum of motor skills, and across the lifespan (Mancini, Rigoli, Cairney et al., 2016; Mancini, Rigoli, Heritage et al., 2016; Wagner et al., 2012; Wilson, Piek, & Kane, 2013). Third, the Environmental Stress Hypothesis is characterized by a complex relationship between motor skills and internalizing problems posited to be mediated and moderated by the presence of numerous factors. The term ‘mediation’ is used to refer to instances where the relationship between motor skills and internalizing problems is explained by an indirect association via alternative indirect pathways. The term ‘moderation’ refers to instances where the strength of this relationship is influenced by the presence of other variables. For example, gender has been found to moderate certain psychosocial outcomes previously examined within the DCD setting (Piek, Barrett, Allen, Jones, & Louise, 2005). Previous research supporting the development of the hypothesized relationships in the Environmental Stress Hypothesis commonly investigated relationships between pairs of variables. Though ongoing evaluation of these direct pathways is important, they are limited in their ability to consider the more complex interaction between multiple components within the framework. This area of emerging literature was recently discussed in a review by Mancini, Rigoli, Cairney et al. (2016); Mancini, Rigoli, Heritage et al. (2016). However, this article served to describe, rather than synthesize the studies that were available in the area at the time of publication. Several additional studies testing complex pathways in the framework have since been published, further advocating for the suitability of an integrative research review.

The aim of the current integrative research review was to bring together individual studies in a single area of research to develop a comprehensive understanding of the current evidence-base for the complex pathways contained within the Environmental Stress Hypothesis. Direct relationships between pairs of variables within the framework are the result of substantial empirical investigation, warranting their own extensive reviews; describing the studies relevant to each pair of relationships in addition to the complex relationships between multiple variables in a single paper would limit the depth that is required to explore such associations. Therefore, this study attends to the emerging research that has investigated the relationships between multiple variables contained within the Environmental Stress Hypothesis. As part of the aim of this research, the strengths and limitations of the current evidence and directions for future research are explored. It could be argued that a meta-analysis may be the best methodology to achieve this goal. However, studies which have tested this framework are relatively limited in number. Furthermore, despite shared theoretical underpinnings, these studies are largely heterogeneous in terms of sample characteristics, variables of interest, and the operationalization and measurement of these variables. A meta-analysis of the currently available literature may result in an undesirable ‘summary effect’ which may conceal potentially important findings that may not be sufficient to alter the generalized results (Lifshitz, Kilberg, & Vakil, 2016). Therefore, we considered the integrative research review as a more appropriate methodology to achieve our study goal.

2. Method

2.1. Research aims

The aim of this integrative research review was to examine the currently published literature that has tested the complex pathways through which motor skills are associated with internalizing problems, as hypothesized by the Environmental Stress Hypothesis (Cairney et al., 2013). We use the term ‘complex pathways’ to refer to mediated and/or moderated associations between motor skills and internalizing problems, and to differentiate this research from studies that have only examined direct relationships between variables.

Physical activity and obesity are important components of the Environmental Stress Hypothesis; this is supported by the extensive body of literature regarding how poor motor skills impact rates of physical activity (Cairney et al., 2005). To adhere to the aims of the current study, we do not include any of these studies unless they also include a measure of motor skills and internalizing problems.

Table 1
Database Search Terms to Screen Literature for the Integrative Research Review.

Database	Search Parameters
Proquest	ti((“motor skills” OR “motor proficiency” OR “motor coordination” OR “motor development” Or “motor ability” OR DCD OR “developmental coordination disorder” OR “Coordination” OR dysprax* OR clums*) AND (well-being OR mental health OR anxi* OR depress* OR “environmental stress” OR self* OR mental OR competence OR psychosocial OR social OR emotional OR health OR Behavio*)) AND (relation* OR associat* OR correlat* OR mediat* OR moderat* OR Outcome)
PsychINFO	(movement OR motor OR DCD OR developmental coordination disorder OR move*) AND (well-being OR mental health OR anxi* OR depress* OR "environmental stress" OR self* OR competence OR psychosocial OR social) AND (relationship OR association OR mediat* OR moderat*)
Web of Science	#1: TI = (relation* OR associat* OR correlat* OR mediat* OR moderat*) Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years #2: TI = (well* OR “mental health” OR anxi* OR depress* OR social OR psychosocial OR emotion* OR health*) Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years #3. TI = (MOTOR OR MOVEMENT OR "DEVELOPMENTAL COORDINATION DISORDER" OR DCD) Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years #4: #3 AND #2 AND #1 Refined by: PUBLICATION YEARS: (2018 OR 2017 OR 2016 OR 2015 OR 2014 OR 2013 OR 2012 OR 2011 OR 2010) Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years
Google Scholar	"MOTOR" "MOVEMENT" "DEVELOPMENTAL COORDINATION DISORDER" "RELATIONSHIP" "EMOTIONAL" "BEHAVIORAL" "BEHAVIOURAL" "MEDIATE" "MODERATE" "ASSOCIATION"
Forward Citation Search	Use of the ‘Cited By’ feature in Google Scholar for two Environmental Stress Hypothesis papers published by Cairney et al. (2010) and Cairney et al. (2013).

Note. Studies required to be published in English language, scholarly journals between 2010 and 2018 to be eligible for inclusion.

2.2. Search and selection strategy

We followed the stages of an integrative research review described by Torraco (2005). This comprises four steps: (1) problem formulation and research aims; (2) literature search and collection of data; (3) data evaluation and analysis; and (4) findings and discussion. Database search terms were developed by each of the researchers involved in the current study (see Table 1 for a list of search terms). Following the development of search terms, a computerized literature search of peer-reviewed studies was performed by one member of the research team in April 2018. Publications were included if they met the following inclusion criteria: (a) empirical studies (or reviews of empirical studies) testing complex relationships between variables included in the Environmental Stress Hypothesis, (b) peer-reviewed and published (or in-press) in English language scholarly journals, and (c) published (or in-press) between 2010 and April 2018. The date range was selected to exclude studies published before the original publication of the Environmental Stress Hypothesis (Cairney et al., 2010). Additional relevant studies were identified through a forward-citation search of the Cairney et al. (2010) and Cairney et al. (2013) publications, and by recommendation from leading experts in the field. The researchers deemed a total of 12 publications as eligible for inclusion in the integrative research review.

A visual depiction of the study selection process is detailed in Fig. 2. The citations from each search source were collated in Endnote X7 referencing software. First, all duplicate studies were removed by one of the researchers. This researcher then deleted any citations that were published prior to 2010, or that were not published in the English language. Next, all non-peer-reviewed sources were deleted. Titles were then screened by the researcher, with all titles not relating to the area of motor skills and mental health removed. For the purposes of this screening process, only papers referring to the psychological, social and emotional dimensions of mental health were included; studies concerned with other areas of mental health (e.g., cognitive functioning) were not included. The abstracts of all appropriate titles were then screened, with only those studies directly relevant to the relationships posited in the Environmental Stress Hypothesis retained. The full-text of each of these studies were screened by the same researcher; any study which did not test complex pathways posited in the Environmental Stress Hypothesis (e.g., studies that simply examined the association between motor skills and internalizing problems without considering possible mediating or moderating factors) was excluded. Twelve studies that provided an evaluation of the complex pathways contained within the framework were retained for analysis in the current paper.

3. Findings and discussion

3.1. Characteristics of the selected articles

The 12 studies that were selected are presented in Table 2. Most of the included studies utilized cross-sectional correlational research designs to evaluate the strength and direction of relationships between variables of interest. Three correlational and two experimental research designs included measures of follow-up.

Community sampling procedures were used in the majority (n = 8) of included studies. In these studies, complex relationships between motor skills, internalizing problems, and selected psychosocial factors were tested across the full continuum of motor ability. Three studies enlisted the use of case-control designs to compare children with DCD to a control group of typically developing peers. The remaining study used a clinical population to evaluate a RCT for children with DCD. Eleven studies involved child or adolescent

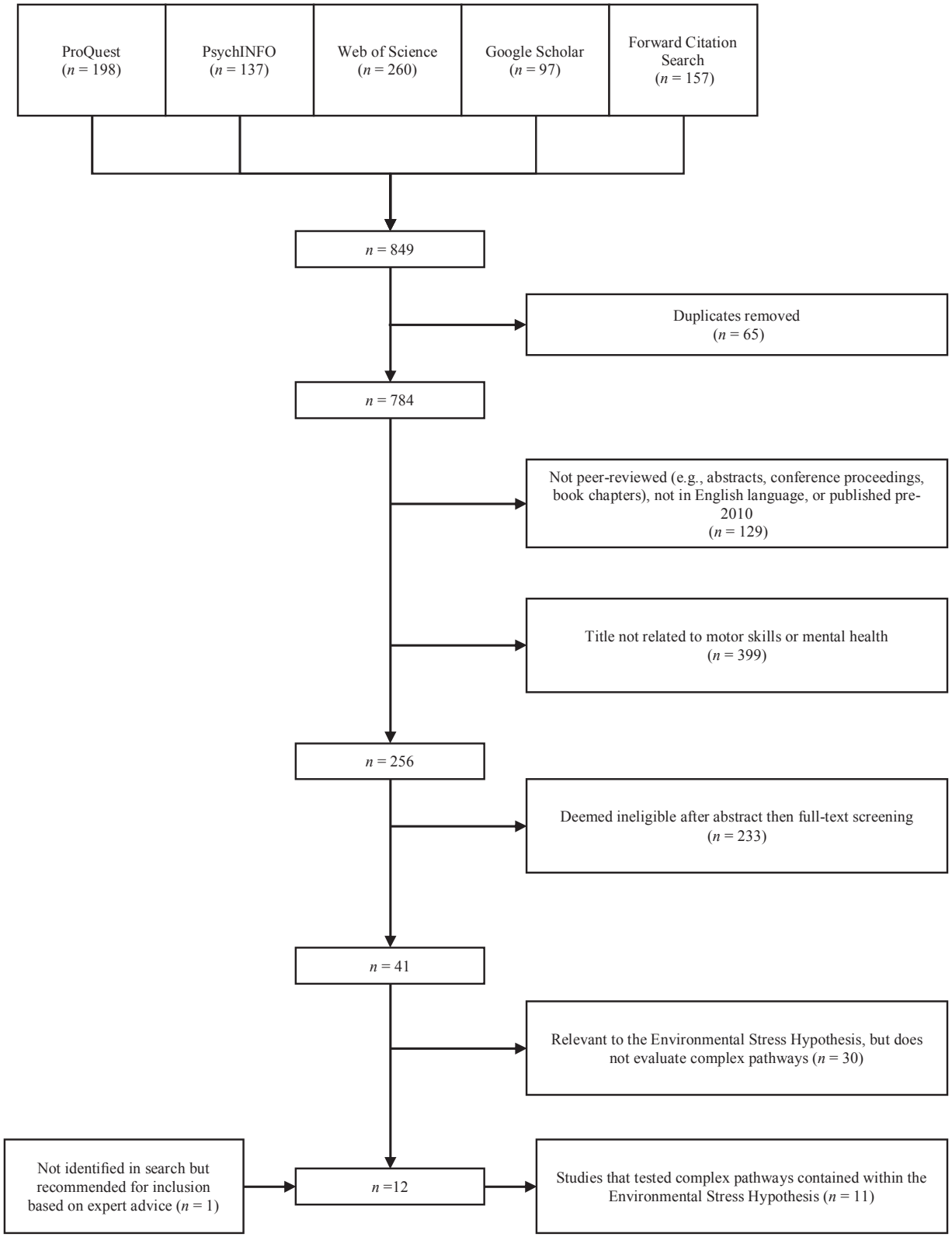

Fig. 2. Visual representation of the study selection process for the current study.

Table 2
Summary of Included Studies (N = 12).

Article	Design	Key Variables	Measures Used	Key Findings	Covariates Included	Country	Quality Rating	Sample Type	Sample N	Mean Age (Range)	Sex	Data Source
Harrowell et al. (2017)	Longitudinal (Correlational)	Motor Skills; Mental Health Difficulties; Social Communication; ADHD symptoms; Social Support; Self-Esteem	Clinician Assessed Motor Skills; Self-Report Measures for all other variables	Childhood DCD is associated with a greater risk of mental health and social difficulties in adolescence; this relationship was partially mediated through poor social communication skills. Females with DCD were at greater risk of mental health difficulties compared to males.	Gender; Gestation; Birthweight; SES; Parental Mental Health;	United Kingdom	10	CO; CH - T	DCD = 168; Control = 3750	Mean not provided. Time 1 Range = 7 to 8 years; Time 2 Range = 16 to 18 years	1889 M; 1861F	Unique
Li et al. (2017)	Correlational (Cross-Sectional)	Motor Skills; Physical Activity; BMI; Global Self-Worth; Internalizing Problems	Clinician Assessed Motor Skills; Self-Rated Measures for all other variables	Direct and indirect pathways from motor skills to internalizing problems via physical activity, global self-worth, and BMI accounts for 21.7% of the variance in internalizing problems. There were significant sex-differences; more mediation pathways for females. Two step mediation from motor skills to physical activity to global self-worth to internalizing problems was observed for males and females. Additional single-mediator pathways via physical activity and global self-worth were observed for females.	Not provided	Canada	9	CO; T	1,206	13.4 years (12 to 14 years)	611 M; 595 F	Unique
						Australia	9	CO; T	93		55 M; 38 F	Shared (A)

(*continued on next page*)

Table 2 (*continued*)

Article	Design	Key Variables	Measures Used	Key Findings	Covariates Included	Country	Quality Rating	Sample Type	Sample N	Mean Age (Range)	Sex	Data Source
Mancini, Rigoli, Cairney et al. (2016); Mancini, Rigoli, Heritage, Roberts, & Piek, 2016)	Correlational (Cross-Sectional)	Motor Skills; Perceived Social Support; Anxious Symptoms; Depressive Symptoms	Clinician Assessed Motor Skills; Self-Rated Measures for all other variables	Significant negative correlation between motor skills and anxiety (r =-.32) and depression (r = -.33). Perceived social support mediated the association between motor skills and depression, but not anxiety.	Age; Gender, ADHD symptoms; Verbal IQ					14.21 years (12 to 16 years)		
(Mancini et al., 2017a)	Correlational (Includes Follow-up)	Motor Skills; Peer Problems; Perceived Physical and Cognitive Competence; Internalizing Problems	Clinician Assessed Motor Skills; Self-Rated Measures for Competence; Teacher-Rated Measures of Peer and Internalizing Problems	Significant negative correlation between motor skills and internalizing problems at Time 1 (r = -.17) and Time 2 (r = -.20). Peer problems mediated this association at Time 1; Peer Problems and Perceived Physical Competence mediated this association at Time 2.	Age, Gender, Verbal IQ	Australia	9	CO; CH	Time 1 = 197; Time 2 = 107	Time 1 = 5.40 years (4.86 to 6.07 years); Time 2 = 6.91 years (6.36 to 7.47 yers)	Time 1 = 102 M, 95 F; Time 2 = 57 M, 50F	Shared (B)
Mancini et al. (2017b)	Correlational (Cross-Sectional)	Motor Skills; Peer Problems; Perceived Self-Competence (six domains); Internalizing Problems	Clinician Assessed Motor Skills; Self-Rated Measures for Competence; Parent-Rated Measures of Peer and Internalizing Problems	Significant negative correlation between motor skills and internalizing problems (r = -.29). Peer problems and perceived scholastic competence mediated this association.	Age, Gender, SES, ADHD Symptoms	Australia	9	CO; CH	164	9.93 years (7 to 12 years)	80 M; 84F	Unique
Noordstar et al. (2017)	Experimental (RCT)	Motor Skills; Self-Perceptions; Physical Activity	Clinician Assessed and Parent-Rated Motor Skills; Objective Measure of Physical Activity (pedometer); Self-Report	Care-as-usual treatment was just as effective as a combined perceived self-competence and motor intervention for children with DCD. Perceived self-competence did not	Not provided	Netherlands	9	CL; CH	31 (20 Intervention; 11 Control)	8 years (range Not provided)	21 M; 10F	Unique

(*continued on next page*)

Table 2 (*continued*)

Article	Design	Key Variables	Measures Used	Key Findings	Covariates Included	Country	Quality Rating	Sample Type	Sample N	Mean Age (Range)	Sex	Data Source
			Measures of Self-Perceptions	differ between groups.								
Piek et al. (2015)	Experimental (RCT)	Motor Skills; Prosocial behaviour; Internalizing Problems	*Animal Fun* Intervention Program; Clinician Assessed Motor Skills; Teacher-Rated Measures for all other variables	Intervention group reported significant improvements in prosocial behavior compared to control group Intervention group did not show significant improved in internalizing problems.	Gender	Australia	8	CO; CH	Time 1 = 486; Time 2 = 456; Time 3; 337	Time 1 = 5.42 years (4.83 - 6.17 years)	257 M; 254F	Shared (B)
Rigoli et al. (2017)	Correlational (Cross-Sectional)	Motor Skills; Perceived Social Support; Physical Self-Worth; Internalizing Problems	Clinician Assessed Motor Skills; Self-Rated Measures for all other variables	Significant negative correlation between motor skills and internalizing problems (r = -.27). Perceived social support mediated the relationship, but not physical self-worth.	Age; Gender; BMI	Australia	9	CO; A	95	21.73 years (18 to 30 years)	35 M; 60 F	Unique
Rigoli et al. (2012)	Correlational (Cross-Sectional)	Motor Skills; Perceived Self-Competence; Internalizing Problems	Clinician Assessed Motor Skills; Self-Rated Measures for all other variables	Significant negative correlation between motor skills and Emotional Functioning (r = .47). Self-perceptions mediated the assocation between motor skills and Emotional Functioning.	Age; Gender, SES, ADHD symptoms; Verbal IQ	Australia	7	CO; T	93	14.21 years (12 to 16 years)	55 M; 38 F	Shared (A)
Viholainen et al. (2014)	Correlational (Cross-Sectional)	Motor Skills; School-Related Self-Concept; Psychosical wellbeing (5 domains)	Self-Report Measure of Motor Skills; Self-Report Measures for all other variables	Motor skills account for 44% of the variance in overall PSWB. Motor Skills and School-related self-concept could account for 31% of the variance in internalizing problems, but this relationship was not mediated.	Not Provided	Finland	7	CO; T	327	Not provided (12 to 16 years)	327F	Unique
Wagner et al. (2012)		Motor Skills; Peer Problems;	Clinician Assessed Motor	Peer problems mediate the	Not provided	Germany	7	CC; CH	70 (35 DCD; 35 Control)	7.69 yers (5 to 11 years)	27 M; 8 F	Unique

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Table 2 (*continued*)

Article	Design	Key Variables	Measures Used	Key Findings	Covariates Included	Country	Quality Rating	Sample Type	Sample N	Mean Age (Range)	Sex	Data Source
	Correlational (Cross-Sectional)	Internalizing/ Externalizing Problems	Skills; Parent-Rated Measures for all other variables	association between motor skills and internalizing/ externalizing problems. The greater the degree of motor impairment, (a) the greater the degree of peer problems ($\beta = 0.281$; $p < 0.01$) and (b) the greater the degree of internalizing ($\beta = 0.318$; $p < 0.01$) and externalizing ($\beta = 0.220$; $p < 0.05$) problems in school-aged children.							
Wilson et al. (2013)	Correlational (Cross-Sectional)	Motor Skills; Social Skills; Internalizing Symptoms	Clinician Assessed Motor Skills; Teacher-Rated Measures for all other variables	Significant negative correlation between motor skills and internalizing problems ($r = -.13$). Social skills mediated this association.	Age; Gender; Verbal IQ	Australia	10	CO; CH	532	5.42 years (4.29 to 6.5 years)	291 M; 241 F	Shared (B)

CO = Community Sample; CL = Clinical Sample; CH = Children; T = Adolescents; A = Adults; M = Male; F = Female; SES = Socioeconomic Status; BMI = Body Mass Index; CC = Case-Control; PSWB = Psychosocial Well-being. Measures of effect size are provided when reported in studies. Studies that share the same data are matched alphabetically in the last column.

Table 3
Modified Critical Appraisal Skills Programme Used to Evaluate Quality of Studies Included in the Current Review.

Item Number	Item Description for Experimental Research Designs	Modified Item Description for Observational Research Designs
1	In the study rationale, is there sufficient acknowledgement of essential aspects of theory and pivotal studies?	In the study rationale, is there sufficient acknowledgement of essential aspects of theory and pivotal studies?
2	Did the study address a clearly focused (theory driven) question?	Did the study address a clearly focused (theory driven) question?
3	Was the research design well chosen to address the research question(s)?	Was the research design well chosen to address the research question(s)?
4	Was sample size sufficient or justified using power calculation?	Was sample size sufficient or justified using power calculation?
5*	Were children with developmental coordination disorder identified/screened appropriately and thus (sufficiently) representative of the population?	Was the motor competence of participants identified/screened appropriately?
6*	Were control children representative of the population?	Was the overall sample sufficiently representative of the population? (If using a community sampling procedure, was the proportion of participants identified as at-risk of DCD consistent with prevalence estimates of approximately 5%?)
7	Were the constructs of interest clearly operationalized and measured?	Were the constructs of interest clearly operationalized and measured?
8	Were major confounds adequately controlled?	Were major confounds adequately controlled?
9	Were the statistical methods appropriate and adequately presented?	Were the statistical methods appropriate and adequately presented?
10	Are the major implications of the results clearly discussed?	Are the major implications of the results clearly discussed?

Items adapted from Wilson et al. (2017).

* A score of 1 was awarded if studies utilized a standardized, clinician administered measure of motor proficiency. Self-report, parent-report or teacher-report measures of motor proficiency were awarded a score of 0 for the purposes of the present study. A score of 0 is provided if the study does not provide sufficient details to answer the question.

populations.

The 12 included articles do not consist of 12 independent study samples. Several of the studies made use of the same cohorts. Three of the currently included articles analyzed data obtained from the same cohort participating in a large-scale RCT (Piek et al., 2010), differentiated by the examined variables and/or phase of data collection. Of the 12 included articles, 9 unique populations contributed data.

3.2. Appraisal of study quality

Study quality was determined using a modified version of a 10-item inventory based on the Critical Appraisal Skills Programme for case-control studies (Singh, 2013; Wilson et al., 2017). Each item is scored as either 1 (confirmed) or 0 (unconfirmed). Studies with higher scores are regarded as being of higher quality. Ratings of 8 or above were deemed as high quality, 5–7 as moderate quality, and less than 5 as low quality (Wilson et al., 2017). This instrument has been used in a previous systematic review of case-control studies within the DCD literature (Wilson et al., 2017). The wording of two items (item 5 and item 6) was modified to allow the instrument to be applied to correlational research designs (see Table 3). Ratings were independently evaluated by two of the current researchers. Agreement of study ratings was 87% indicating good levels of agreement. Any instances of disagreement were resolved through discussion amongst the authorship team to reach consensus. The average quality rating for included studies was 8.58 (SD = 1.08).

3.3. Direction and effect size

The Environmental Stress Hypothesis posits a negative association between motor skills and psychosocial difficulties, whereby poorer motor skills are related to higher levels of psychosocial impairment (e.g., higher internalizing problems, greater peer problems, decreased self-competence). Each of the included studies identified either at least one significant relationship between motor skills and psychosocial factors that was consistent with this inverse association, providing at least partial support for the Environmental Stress Hypothesis pathways. The studies that tested several indirect pathways seldom identified support for all of the relationships that were examined (e.g., Rigoli et al., 2017). The findings suggest that certain factors (i.e., interpersonal factors) appear to be consistently identified as important mediators, whereas mixed support for other mediators were identified (i.e., perceived self-competence). These findings may be due to differences in sample characteristics and measures used. For example, ratings of emotional and behavioural problems in children with DCD have been shown to vary between teacher and parent-reports, both of which have been used in the included articles (Crane, Sumner, & Hill, 2017). The discrepancies between informants (e.g., teacher, parent, self) may compromise the consistency of findings across studies. In addition to issues related to sampling and measurement, there is preliminary suggestion that the relationships posited in the Environmental Stress Hypothesis may be dynamic across the lifespan or due to other factors (Mancini, Rigoli, Roberts, Heritage, & Piek, 2017). Longitudinal research, and studies that examine possible moderating effects of variables (e.g., gender) are required in order to further explore this association. None of the included studies identified the opposite association, whereby poorer motor skills were significantly associated with better psychosocial

functioning.

Where reported (or calculable) measures of effect size for the relationship between motor skills and internalizing problems were identified for each of the included studies. With a primarily correlational body of literature, the effect size was most commonly evaluated using Pearson's *r* coefficient and interpreted according to the conventions set out by Cohen (1992). Among these studies, the relationship between motor skills and internalizing problems ranged from small to moderately-sized negative associations, with observed *r* values ranging from −0.13 to −.47. However, the strength of the mediation was seldom reported. It should be noted that these cross-sectional, correlational research designs that identified small to moderate relationships between motor skills and internalizing problems enlisted community samples. The current findings are unable to infer the strength of this association in clinical populations, such as those with DCD.

These small-to-moderate effect sizes also suggests that a large proportion of variance in internalizing problems remains unexplained by motor skills, and the psychosocial factors thought to mediate this relationship. These findings further highlight the need to test multiple predictors posited in the Environmental Stress Hypothesis. More importantly, the current findings also advocate for the inclusion of factors that were not originally included in the framework. For example, resilience is a disposition that promotes positive functioning in response to challenges or adversity (Pinquart, 2009) that may be highly relevant to this area of investigation. Resilience has been considered in the DCD literature as a plausible moderator of the relationship between poor motor skills and psychosocial functioning, yet remains underexplored (Lingam et al., 2012). Cairney et al. (2013) describe the Environmental Stress Hypothesis as a flexible framework that can capture processes beyond those specifically identified in this paper, suggesting that additional factors should also be considered in the context of this framework.

3.4. Multiple indirect pathways

The Environmental Stress Hypothesis provides several indirect pathways through which motor skills are posited to be associated with internalizing problems. Each of the included studies provides only a partial evaluation of these pathways, often testing the hypothesized indirect effect through one or two of the posited variables (e.g., Mancini, Rigoli, Roberts, Heritage, & Piek, 2017; Wagner et al., 2012). Five of the included studies investigated multiple indirect pathways. One general finding was that motor skills were more consistently and strongly associated with internalizing problems via interpersonal factors (i.e., peer problems, perceived social support), compared to domains of self-competence. General perceived self-competence was also found to mediate the relationship between motor skills and internalizing problems in one of the included studies (Rigoli, Piek, & Kane, 2012). However, there are several domains thought to comprise general perceived self-competence (e.g., physical competence, cognitive competence, social competence). These domains were investigated in several of the current studies (Mancini et al., 2017b; Viholainen, Aro, Purtsi, Tolvanen, & Cantell, 2014). The included articles provided support for both perceived physical self-competence (Mancini et al., 2017a) and scholastic or school-related self-competence (Mancini et al., 2017b; Viholainen et al., 2014). One potential explanation for these associations is that motor skill deficits may contribute to both poor physical self-competence and also poor perceptions of one's scholastic ability that might occur due to academic activities (e.g., handwriting, participating in physical eduation class).The current articles did not provide consistent support for these observed relationships. This finding may be attributed to the use of different samples and different measures used across studies. However, an alternative explanation may be that the strength and pattern of relationships between motor skills and psychosocial factors are dynamic, and change throughout the lifespan (Mancini et al., 2017a). One of the incldued studies provided preliminary support, a relationship between motor skills and internalizing problems was mediated by peer-problems in a sample of young children (4–6 years); this relationship was mediated by peer problems and perceived physical self-competence at 18-month follow-up (Mancini et al., 2017a). The authors suggested that important cognitive developmental milestones that occurred around this period (i.e., greater self-awareness relative to peers) allowed children to evaluate their motor competence to their peers. However, this argument remains largely theoretical and requires further longitudinal investigation.

The relationship between mediator variables have not yet been evaluated in the context of the Environmental Stress Hypothesis. Studies that have investigated the impact of several mediator variables have assumed that these factors are independent. This represents a current limitation, as well-established relationships exist between several of the hypothesized mediating/moderating variables (Li et al., 2017). For example, one of the included studies tested the mediating effects of perceived social support and physical self-worth, but did not consider how one of these factors may influence the other (Rigoli et al., 2017)

3.5. Moderator variables

Cairney et al. (2013) suggested that the intermediary factors between motor skills and internalizing problems may mediate and moderate this relationship. The moderating role of these variables was not evaluated in any of the selected articles, with emphasis instead placed on testing mediating relationships. Several studies screened basic demographic information (age and sex) as potential moderators based on earlier literature, but subsequently excluded them from further analyses based on non-significant associations with measurement variables (e.g., Wilson et al., 2013) or included these factors as covariates when testing indirect relationships (e.g., Mancini et al., 2017b). The extent to which the variables included in the Environmental Stress Hypothesis or other variables (e.g., gender) moderate the hypothesized associations remains underexplored and should be evaluated as part of future research initiatives.

3.6. Causality

Though the Environmental Stress Hypothesis is a causal framework, most of the supporting evidence has been generated from cross-sectional, correlational research designs that cannot be used to infer causality. Results are often interpreted in the context of previous experimental studies that have provided support for a causal relationship between motor skills and internalizing problems (e.g., Piek et al., 2007; Waszczuk et al., 2016). However, the current findings are insufficient indicators of causality. Hypothesized associations were often supported, though directionality and causal underpinnings remain underexplored. The limited body of experimental research pertaining to the Environmental Stress Hypothesis has identified that while improvements in motor skills can improve certain psychosocial factors (e.g., prosocial behavior), no improvements in internalizing problems were noted (Piek et al., 2015). Establishing temporal precedence is an integral component of establishing causality between motor skills and internalizing problems. To date, only one published study has longitudinally evaluated the Environmental Stress Hypothesis, providing evidence of temporal precedence for direct relationships contained within the framework from childhood into adolescence (Wagner et al., 2016). However, this study did not test the complex pathways posited in the framework.

3.7. Implications for intervention research

An advantage of motor skill interventions is the potential to establish causal relationships between motor skills and psychosocial factors (including the complex associations posited in the Environmental Stress Hypothesis), while also granting individuals the possible benefits of intervention strategies (Yu, Burnett, & Sit, 2018). Missiuna and Campbell (2014) stated: "If, as suggested by Cairney et al. (2010,2013), there are "intermediary" factors that can mediate or change the mental health trajectory of children with DCD, then another way of establishing causality would be to trial interventions that target potential mediating variables and then monitor psychological outcomes" (p. 128).

Two of the included studies evaluated the effectiveness of interventions targeting both psychosocial and motor (termed 'psychomotor') functioning in children. The first study (Piek et al., 2015) found that a community-based psychomotor intervention did not improve internalizing symptoms but did significantly improve pro-social behavior. The authors suggest that the effects of this intervention on the emotional functioning of children may not be immediate, and instead occur over time (Piek et al., 2015). This is consistent with the idea that motor proficiency engenders positive and protective psychosocial experiences, such as the development of friendships and self-competence (Campbell et al., 2012; Mandich, Polatajko, & Rodger, 2003). However, we argue that an additional explanation for no significant effect on internalizing problems relates to the target intervention population. The *Animal Fun* intervention (Piek et al., 2010) used in Piek et al. (2015) was designed for implementation amongst all school-aged children, not only children with DCD. For children who show intact motor skills, a psychomotor intervention program may yield comparatively less effectiveness compared to children with DCD. Consequently, analyses that treat the sample as a homogenous population may overlook important changes that occur in the subgroup of children with poor motor skills. Piek et al. (2015) demonstrated that the benefits of psychomotor interventions were not limited to only children with DCD, however future evaluation of community-based interventions should also consider analyses of effectiveness amongst at-risk subpopulations.

The second intervention study (Noordstar, van der Net, Voerman, Helders, & Jongmans, 2017) compared a care-as-usual treatment for DCD (comprised of conventional practicing of the identified deficient motor activities; $n = 11$) to an intervention comprised of a modified care-as-usual treatment that also aimed to enhance the child's perceived athletic competence by using goal setting; positive, specific, and progress feedback; and by making the child more aware of their progress ($n = 20$). Results yielded no significant differences between intervention and control groups on any of the outcome variables (motor skills, self-perceptions, or physical activity), suggesting that the study's efforts to improve the athletic self-competence of children with DCD were ineffective. However, the authors rightfully recognized threats to the internal validity of their study, namely the large intra-group variability, small sample size, and potential for contamination between conditions (care-as-usual practitioners may have unintentionally enhanced the perceived athletic competence of the control group). Contradictory findings have been identified in an earlier intervention study by Peens, Pienaar, and Nienaber (2008). Using a similarly sized sample ($n = 68$; randomly allocated into four conditions), results showed that participants who received a psychomotor intervention (targeting motor skills and self-concept) reported more positive outcomes (in motor proficiency and self-concept), compared to a control group of no intervention. The motor skills only treatment group did not show any significant improvement in self-concept, and the self-concept treatment only group did not show any significant improvement in motor skills. These findings suggest that combined psychomotor intervention programs for children with DCD may yield optimal benefits. The psychomotor intervention group also reported a decrease in anxiety, though this was non-significant (Peens et al., 2008). It may again be important to consider the limitations associated with a smaller sample size inflating the risk of Type II error, particularly considering most studies have identified small to moderate negative associations between motor skills and internalizing problems. A related study by McIntyre et al. (2015) found that an exercise intervention for adolescents with low motor competence improved physical self-perceptions. However, no measures of internalizing problems (or other mental health outcomes were reported), thus the ensuing benefits of improved physical self-competence, which may plausibly include improvements in internalizing problems, were not explored.

Framing the current intervention literature within the Environmental Stress Hypothesis, the current findings suggest that studies involving psychomotor intervention programs that target the motor skills and self-competence of children with DCD have not been able to significantly improve internalizing problems (Noordstar et al., 2017; Peens et al., 2008). However, self-competence is only one of several intermediary factors posited to mediate this relationship; the Environmental Stress Hypothesis provides several factors that remain untested within the intervention literature. Based on the findings included in the current paper, we argue that interpersonal

Table 4
Threats to Validity Identified by Russell (2005) and Measures Taken to Minimize Threats in the Current Study.

Phase	Threat to Validity	Measures Taken to Minimize Threat
Problem Formulation	1. Operational definitions too narrow or broad	Including studies relevant to motor coordination (not just DCD); and including studies that have tested complex pathways consistent with the Environmental Stress Hypothesis without having specifically cited the framework (e.g., Viholainen et al., 2014)
Data Collection	2. Inadequate Sampling 3. Discrepancy between collected studies and target population	A range of search terms spanning multiple databases, forward citations search of the Cairney et al. (2010) and Cairney et al. (2013) papers, and expert recommendation were all measures taken to maximize the data collected as part of the current study. Furthermore, transparency was maximized by appropriately citing each study and describing the study samples (Russell, 2005).
Data Evaluation	4. Confirmation bias of the researcher's own beliefs	Including a measure of study quality
Data Analysis	5. Undertaking incorrect secondary analyses 6. Inferring causality	Describing results of studies; only reporting statistics that were provided (or easily calculated); not making causal inferences
Interpretation and Presentation	7. Omission of important information to inhibit replicability	Provided enhanced description of the study procedure

factors (e.g., peer problems and perceived social support) are integral targets for future intervention programs. Correlational studies that have evaluated the mediating effects of both perceived self-competence and interpersonal factors (either peer problems, or perceived social support) have shown that the interpersonal factors were more strongly associated with both motor skills and internalizing problems, and mediated this relationship when self-competence did not (Mancini et al., 2017a, 2017b; Rigoli et al., 2017). We hypothesize that psychomotor intervention efforts that aim to engender social support (e.g., through the formation of friendships, improving social skills) are likely to improve internalizing problems, among other positive benefits.

An additional way in which intervention programs could help to investigate causal relationships between motor skills and internalizing problems is to include measures of motor skills as part of interventions for internalizing problems. Contrary to the hypothesized causal trajectory from motor skills to internalizing problems (Cairney et al., 2013), an alternative hypothesis is that children who are less anxious may be more willing to engage in activities that can enhance motor proficiency (e.g., participating in unstructured and structured play with peers). These rival hypotheses should be tested before the relationships posited in the Environmental Stress Hypothesis can be regarded as causal. Future studies could test this association using a similar technique to Peens et al. (2008), where the outcomes of four groups are compared to establish temporal precedence: (a) motor skills only intervention, (b) internalizing problems only intervention, (c) combined psychomotor intervention, (d) control group.

3.8. Threats to internal validity

Russell (2005) outlined key threats to the validity of an integrative research review at each point of the methodological process. Researchers in the current study endeavored to minimize these threats; these are described in Table 4. However, some additional threats to internal validity should be noted. The search and selection process was performed by one researcher, with all researchers approving the final list of included studies. The inclusion of a second researcher to participate in the search and selection process as a triangulation procedure may help to provide greater confidence in the appropriateness of included/excluded studies. The current study also restricted the inclusion criteria to peer-reviewed journal articles published in the English language. Therefore, we are unable to account for possible publication bias or relevant studies that were published in other language journals or unpublished studies. Greater attention should be placed on these other sources of literature in future research.

4. Conclusion

The Environmental Stress Hypothesis is a theoretical framework that argues poor motor skills are an indirect cause of internalizing problems via several factors that mediate and/or moderate this association. The aim of this integrative research review was to evaluate the studies that had tested these complex pathways. Through a systematic search of the literature, 12 published studies evaluating these relationships were identified. Results revealed there was partial support for the Environmental Stress Hypothesis; most studies were correlational, cross-sectional research designs. One overall finding was that the effect sizes of the relationship between motor skills and internalizing problems were small to moderately-sized. The second finding was an indirect association from motor skills to internalizing problems in most studies, though the factors responsible for this indirect effect appear to vary between study populations. This may be due to issues related to sampling or measurement, but may also be explained by the dynamic nature of motor and psychosocial development (e.g., Mancini et al., 2017a). These preliminary findings suggest that interpersonal factors (e.g., social support, peer problems) are a stronger and more consistent mediator compared to self-competence. Certain pathways, including hypothesized moderating effects, remain empirically under-examined. Correlational research cannot be used to infer causation and experimental research is required to identify whether the Environmental Stress Hypothesis is a truly causal framework. The development and evaluation of psychomotor interventions targeting factors within the framework will provide a platform to test causal hypotheses while attempting to improve the physical and psychosocial outcomes of intervention groups.

Conflict of interest

The study authors have no conflict of interest to declare.

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