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REVIEW

A Systematic Review of Neurodevelopmental Assessments in Infancy and Early Childhood: Developing a Conceptual Framework, Repository of Measures, and Clinical Recommendations

Bianca C. Bondi[1] · Vanessa K. Tassone[1] · Oana Bucsea[1] · Mary Desrocher[1] · Debra J. Pepler[1]

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Abstract
The first 6 years of life are when 90% of brain development occurs, setting the foundation for lifelong neurodevelopment. The field of infant and early childhood neurodevelopment has made marginal advancements since introduced in 1988. There remains a gap in knowledge around early neurodevelopmental domains and trajectories given that there are few established assessment procedures for infants and young children and controversies around reserving assessments until school age. Throughout this systematic review, we (1) identified neurodevelopmental assessment measures employed in the literature by domain and age of assessment, (2) compiled a repository of 608 domain-specific neurodevelopmental assessment measures, and (3) established a preliminary conceptual framework for cross-domain neurodevelopmental assessments across infancy and early childhood. This review adhered to PRISMA guidelines and spanned three databases (PsycINFO, MEDLINE, PubMed). Articles were reviewed for (1) infancy and early childhood (0–6 years), (2) neurodevelopmental measures, and (3) English language. This systematic review spanned 795 articles from 1978 to 2020 with international representation. Advancements in assessment methods (e.g. measures, domains, frameworks) are essential for the evaluation of early neurodevelopmental profiles to inform early interventions, thus harnessing the neuroplasticity and dynamic development notable during early childhood. We hope this work catalyzes future research and clinical guidelines around early assessments methods.

Keywords Neurodevelopment · Neuropsychology · Assessment · Infancy · Early Childhood · Systematic Review

Introduction

Infant and Early Childhood Neurodevelopmental Assessments

The field of infant and early childhood neurodevelopment has made marginal advancements since first introduced in 1988 as 'the assessment of brain-behavior relationships in the context of developmental change and maturation' across the neonatal, infancy, and toddler/preschool periods (i.e. age 0–6 years) (Aylward, 1988, p. 226). It is challenging to assess neurodevelopmental functioning in infancy and early childhood given that it occurs against a backdrop of developmental, behavioural, and structural changes (Aylward, 1988, 1997b, 2004a; Johnson, 2001). Early neurodevelopmental assessments differ from traditional developmental assessments in that there is a greater emphasis placed on evaluating the underlying neuropsychological mechanisms that capture the interplay between development, recovery of function, and biological and environmental influences (Aylward, 1997b; Chugani et al., 1996; Johnson, 2001). Additionally, there is a greater emphasis placed on evaluating differing functional areas above and beyond developmental, social-emotional, and adaptive functioning domains alone (Aylward, 1988). Early neurodevelopmental assessments also differ from neuropsychological assessments with school-aged children given that infancy and early childhood are characterized by rapid development and neuroplasticity (Anderson et al., 2011; Chugani et al., 1996; Galván, 2010). This developmental context is characterized by a high velocity for change which necessitates age-specific, mixed-method, and individualized evaluations (Aylward, 2004a; Bullins et al., 2016). Additionally, since development is dynamic and ongoing with different critical and sensitive

✉ Bianca C. Bondi
bbondi@yorku.ca

[1] Department of Psychology, York University, 4700 Keele Street, Toronto, ON M3J 1P3, Canada

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periods for different capacities, the relationship between neural mechanisms and functional abilities is less clear in early childhood (Johnson, 2001, 2011). This ambiguity makes it challenging to identify brain-behaviour relationships across key neuropsychological domains and to predict future functioning (Aylward, 1988).

Early Structural and Functional Brain Development

The infancy and early childhood period is when the most rapid brain growth occurs, which contributes to unique and prolonged neurodevelopment that is marked by the fine-tuning of circuitry (Bullins et al., 2016; McCain, 2020). More specifically, glial proliferation, axonal formation, and dendritic arborization result in dramatic increases in brain volume and cortical surface areas, while synaptic pruning acts to regulate these processes (Gilmore et al., 2007; Knickmeyer et al., 2008; Lyall et al., 2015). Concurrently, myelination increases white matter volume and the maturation of microstructural integrity along neural tracts (Geng et al., 2012; Knickmeyer et al., 2008). As such, the brain experiences the most rapid growth in the first 2 years of life, doubling in size and reaching 80% of adult volume (Knickmeyer et al., 2008). The brain continues to grow and reshape itself from ages 2 to 6 years, reaching 90% of adult volume (Lenroot & Giedd, 2006). The development of grey and white matter via synaptogenesis, pruning, synaptic remodeling, and myelination are foundational to the establishment of neural circuits (Bullins et al., 2016).

The functional development of the brain during early childhood is just as complex and dynamic as its anatomical development (Bullins et al., 2016; Johnson, 2001, 2011). Cortical activity increases and the topology/structure of the brain networks develops rapidly, as seen via the increase in density of long-form connections from 25% at birth to 46% in the first year of life (Gao et al., 2011). Notably, different connection hubs are evident in early childhood relative to adulthood, with infants showing hubs in regions associated with motor and visual skills while adults have hubs in higher-order processing regions (Gao et al., 2011). Furthermore, networks at birth interact and house similar functions but become progressively more specialized to their specific roles through experience and learning, contributing to new and distinct functional abilities across development as networks obtain more spatial overlap (Gao et al., 2013). Theories on functional brain development have illustrated that postnatal development includes the unfolding of maturational sequences ('maturational viewpoint') and neuronal skill acquisition patterns that mirror those in adulthood ('skill learning' theory), in addition to activity-dependent processes wherein emerging functions are due to patterns of interactions between different regions ('interactive specialization') (Johnson, 2001, 2011). Moreover, the neural pathways established in infancy and early childhood set the foundation for future, more complex abilities such that they continue to be built upon and remodeled via mechanisms of plasticity and learning across the lifespan (Bullins et al., 2016). More specifically, development and learning induce robust structural and functional plasticity in neural systems and are thought to exist on a continuum, each independently and simultaneously influencing neural plasticity (Galván, 2010). Taken together, sensory, motor, and cognitive capacities that develop in the early years interconnect to form important prerequisites for success in school, the workplace, and the community (Centre on the Developing Child, 2008; Famri et al., 2007). As such, development from 0 to 6 years is foundational for increasingly complex developmental capacities across the lifespan (Centre on the Developing Child, 2008; McCain, 2020), as well as economic development as capable children contribute to a prosperous society (Famri et al., 2007).

The Need for Early Neurodevelopmental Assessments

In recognizing the dynamic and complex nature of early brain development structurally and functionally, early neurodevelopmental assessments have many functional applications, including determining the early neurodevelopmental status of infants and young children, identifying children who would benefit from early intervention supports, evaluating outcomes post-medical procedures/interventions, documenting changes in neurodevelopmental status over time, predicting later levels of functioning and prognoses, and yielding information about early brain-behaviour relationships (Aylward, 1988, 1997b). The early developmental period can be seen as a window of opportunity in which prevention and early intervention supports can harness neuroplasticity to maximize neurodevelopmental trajectories across the lifespan. The need for early neurodevelopmental assessments has increased in response to advancements in neonatology and pediatrics, which have contributed to increased life expectancy, with a shift toward understanding neurodevelopmental morbidity and enhancing quality of life (Aylward, 1997b). As such, neuropsychologically attuned early assessments are most relevant when working with populations of children who have experienced environmental and biological risks, specifically central nervous system injury, as they may later manifest neuropsychological deficits. Pediatric neuropsychologists are well-suited to identify emergent delays or dysfunctions following adverse effects on brain development in the early years before school entry (Baron & Anderson, 2012). Nonetheless, more than three decades after the inception of the field of infant and early childhood neurodevelopment, stagnancy remains, such that recent literature continues to criticize the sparse attention and limited resources allocated to advance early assessment

methods (Baron & Anderson, 2012; Baron & Leonberger, 2012; Brito et al., 2019).

Barriers in Establishing Early Neurodevelopmental Assessment Methods

Numerous limitations contribute to the lack of early neurodevelopmental assessment methods for infants and young children. Given that infancy and early childhood are characterized by high velocity developmental change, expanding behavioural repertoires, and gradual divergence and differentiation of abilities, there is limited understanding around the early developmental course (Nagle, 2004) and brain-behaviour functions (Baron, 2017). A recurring limitation in the field is thus a lack of a conceptual framework to guide assessment methods and best practice recommendations across the infancy and early childhood period from a neuropsychological lens (Aylward, 1988, 1997b; Mrakotsky & Heffelfinger, 2006).

Despite a clear call for mixed-method assessments, existing neuropsychological assessments during the early childhood period are limited in their ability to consider the influence of qualitative (e.g. observations, collateral reporting, interview reports) in addition to quantitative (e.g. standardized test scores and rating forms) factors on development given a strong reliance on standardized measures alone at school-age (Aylward, 1988, 1997a, b). As such, there has been a proposed shift toward alternative and nontraditional methods including more observational and play-based assessments (Nagle, 2004) that better capture qualitative influences like environmental and relational factors which are essential in early development. In addition to challenges incorporating qualitative factors into early assessments, quantitative components of early neurodevelopmental assessments have also been criticized for lacking standardized, developmentally suitable psychological instruments with appropriate psychometric properties (i.e. reliability and validity) and normative data across relevant domains (Aylward, 1997b, 2004a; Baron, 2017; Baron & Anderson, 2012; Bracken, 1987; Heffelfinger & Koop, 2009; Mrakotsky & Heffelfinger, 2006; Nagle, 2004). The weak predictive validity of measures specific to early childhood (Aylward, 2004b; Colombo, 1993; Hack et al., 2005) has contributed towards the prevailing opinion that reliable measurement of a child's neurodevelopmental abilities cannot be obtained until 4 or 5 years of age (Sattler, 1988). Nonetheless, the weak predictive validity can also be attributed to the emergence of neurodevelopmental deficits over time as abilities become more differentiated and as environmental and relational influences take effect (Aylward, 1988; Galván, 2010).

Moreover, young children tend to be more challenging to assess given the strong influence of behavioural state, temperament, and compliance on performance (Aylward, 1988), as well as limits to their motor, language, and socio-emotional skills (Brito et al., 2019). This is evidenced in that refusal and uncooperative behaviours occur in 12–18% of infants and toddlers during testing, which is much higher than proportions seen in older children and adolescents (Aylward, 2004a). Nevertheless, children deemed to be 'untestable' at an early age due to behavioural and compliance concerns are at heightened risk of emerging neurodevelopmental challenges with age (Langkamp & Brazy, 1999; Wocadlo & Rieger, 2000), thus most in need of early assessment and intervention. Early assessments are also complicated by the need to involve caregivers directly within testing, at times relying on them to help elicit the young child's functional abilities (Nagle, 2004). Discrepancies in scoring are greatest at young ages, which makes it hard to determine whether observed capacities represent the child's optimum performance. Furthermore, traditional reliability measures used at school-age are not designed to take these early developmental considerations into account (Aylward, 1988). The emerging differentiation of functional developmental systems across early childhood also contributes toward greater variability within and across individuals in testing (Brito et al., 2019; Karmiloff-Smith, 2018). Moreover, in light of the unique skillset necessary to test young children, advancement of this assessment field has been hindered by limited graduate-level training in early developmental issues (Aylward, 2004a; Baron, 2017; Baron & Anderson, 2012), and limited practical experience in testing techniques to ensure valid evaluation of infants and young children (Baron, 2017; Baron & Anderson, 2012).

These challenges contribute to infrequent referrals of young children for clinical neuropsychological evaluations relative to older children (Baron & Anderson, 2012). Likewise, alongside long psychological waitlists and limited resources, especially within overburdened public sectors and systems that require diagnoses to access school/clinical supports, it may be challenging to prioritize early assessments. Furthermore, early assessment may be further delayed given that young children often present with less emergent deficits given their dynamic and ongoing development and they do not yet meet diagnostic requirements because of their young age. The challenges in assessing young children have led to an inaccurate perception within the field that neurodevelopmental or neuropsychological assessments are not an effective use of the limited clinical resources available before school-age, when deficits are more likely to become explicitly apparent, functionally debilitating, and diagnostically available (Baron & Anderson, 2012). As a result, infants and young children are often assessed from a developmental lens, rather than a neuropsychological lens (Baron, 2017) despite the importance of considering brain-behaviour relationships alongside early and dynamic brain development and injury.

Although the literature within the field has been dominated by discourse around challenges contributing to a lack of early childhood assessment methods over recent decades, there has been progress highlighted. Assessment instruments for young children have improved considerably (Baron & Leonberger, 2012), including conceptual discussions and designs of tests for some complex capacities (e.g. executive functioning, attention; Diamond, 2012, 2013; Espy et al., 2001) for children 0–6 years (Heffelfinger & Koop, 2009). Specifically, advances have been made in test construction, including well-stratified normative data for young children, clinicians with training and experience to evaluate young children, and cross-discipline interest in normal developmental course and adverse effects of disease/disorder incurred at young ages (Baron & Leonberger, 2012; Johnson, 2001, 2011). Moreover, some preliminary work has indicated increasing levels of stability for specific neurodevelopmental capacities including executive functioning in preschoolers (Carlson, 2005) and effortful control in infants (Posner & Rothbart, 2000). Likewise, preliminary indication of predictive validity has been reported for cognitive and working memory capacities predicting academic achievement across pre-school to school-age children (Alloway & Alloway, 2010), as well as for information processing predicting cognitive and academic achievement across infancy to adolescence and emerging adulthood (Fagan et al., 2007). These preliminary reports of stability and consistency in findings across various capacities and developmental stages highlight the need for future research across other capacities and age frames given the importance of early testing as a means of evaluating current and future functioning (Brito et al., 2019).

The Cost of Stagnancy in the Field

Nonetheless, there remains a gap in knowledge around early neurodevelopmental domains and trajectories given the lack of established assessment procedures for infants and young children. Early assessments are essential to delineate neurodevelopmental profiles and to inform early intervention and educational programming during this vulnerable period in a manner that can harness neuroplasticity to maximize neurodevelopmental trajectories and school readiness (McCain, 2020). However, given the current limitations and stagnancy in the field, most children are not assessed until school-age (Heffelfinger & Koop, 2009; McCain, 2020). Given rapid early development and brain plasticity in the 0–6 years period (Galván, 2010; McCain, 2020), assessments at school-age have less efficacy in altering neurodevelopmental trajectories (Anderson et al., 2000, 2001; Famri et al., 2007; Max et al., 2003; Nass, 1997). The cost of stagnancy is high as, globally, over 53 million children under the age of 5 years were estimated to have developmental disabilities in 2016, with profound lifelong consequences noted (Olusanya et al., 2022). Moreover, the likelihood of a child having a developmental disability before the age of 5 years was at least 10 times higher than that of dying before the age of 5 years in 2019 (GBD, 2019 Diseases and Injuries Collaborators, 2020). To date, the significant gains in childhood survival (~60% reduced mortality since 1990; United Nations Inter-Agency Group for Child Mortality Estimation, 2017) have yet to be matched by similar improvements in the wellbeing of young children with developmental disabilities, with global funding for early childhood development having declined by 11.4% between 2007 and 2016, with no improvements since (Arregoces et al., 2019; Olusanya et al., 2022). Therefore, in failing to prioritize early development, we are failing our children and our future.

The Current Review

Given the current state of the field of infant and early childhood assessment, the objectives of this systematic review were to (1) identify neurodevelopmental assessment measures employed in the research literature across infancy and early childhood, (2) compile a repository of domain-specific neurodevelopmental assessment measures, and (3) establish a preliminary conceptual framework for cross-domain neurodevelopmental assessments across infancy and early childhood. We also discuss clinical recommendations and next steps for the field of infant and early childhood neurodevelopmental assessment. In light of the lack of existing systematic reviews on this topic to date, despite discourse on the field spanning decades, we endeavoured to capture the breadth of knowledge in this field, with future research called upon to take an in-depth approach.

Methods

This systematic review was conducted and reported in adherence with the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) guidelines (see supplemental document Table S1 for PRISMA checklist; Moher et al., 2009; Page et al., 2021). Prior to commencing the review, a protocol was pre-specified and registered with PROSPERO (registration number CRD42020178021; initial registration dated 12/04/2020; updated review progress documented via version history record; Bondi et al., 2020). To be included in the systematic review, studies were required to report on neurodevelopmental assessment measures utilized across infancy and early childhood (i.e. 0–6 years). Specific details regarding eligibility criteria are provided below.

Information Sources and Search Strategy

Study searches were conducted using the Ovid search interface in PsycINFO (1806 to present) and MEDLINE (1946 to present), which includes PubMed. The search strategy included Medical Subject Headings (MeSH). The database search end date was April 7, 2020. The search strategy was developed in consultation with an academic librarian and was designed to capture a broad array of studies that included neurodevelopmental assessment measures that were used in infant and early childhood samples (i.e. 0–6 years; including studies where neurodevelopmental assessment methods in infancy and early childhood was not the primary aim). Numerous text word searches were generated to capture synonymous phrases and nomenclature. All synonymous terms and phrases were combined first using the Boolean 'OR'. The concept of infancy and early childhood from age 0–6 years was searched using database 'Limits'. In all databases, the relevant ages were also searched as text words. The broad concepts of 'neurodevelopmental assessments' and 'infancy and early childhood; 0–6 years' were then combined with the Boolean 'AND'. In all databases, both adjacency operators and truncation symbols were used in text word searches, when appropriate, to capture variant endings of the search terms and variant spellings and phrases. English language, human studies, and full-text peer-reviewed publication (i.e. primary articles and review articles) restrictions were applied using database 'Limits'. No date restrictions were applied to ensure maximum yield of relevant papers in light of no known review on this topic to date. The complete search strategy for each database is outlined in the supplementary material (Table S2).

Eligibility Criteria and Selection Process

The Covidence program (Veritas Health Innovation, 2019) was used for all article screening based on the following eligibility criteria: (1) standardized neurodevelopmental assessment measures such that the measures were formal assessment tools (e.g. questionnaires, semi-structured/structured interviews, observational measures, administered assessment measures) used to evaluate child-specific neurodevelopmental outcomes rather than experimental paradigm tasks, (2) infancy and early childhood period (0–6 years) at assessment, (3) published in English, (4) full-text peer-reviewed publication (primary articles, review articles). Studies were excluded for the following reasons: (1) no child-specific neurodevelopmental assessment measure (medical assessment measures, family or population-based measures rather than child-specific measures, animal measures), (2) unstandardized neurodevelopmental assessment measure (experimental paradigm), (3) assessment measure not specified or vague, (4) sample above age 6 years at time of assessment, (5) age at assessment not specified or not able to be computed, (6) review article with target age for assessment measure(s) not specified, and (7) not in full-text article form or full-text article not available. The titles and abstracts of the identified records were screened by two independent reviewers (i.e. BCB and OB) to determine whether the study met the pre-specified inclusion/exclusion criteria. Potentially eligible articles then underwent full-text screening by two independent reviewers (i.e. BCB and OB). Disagreements were settled by discussion and consensus.

Data Extraction

Data were extracted by a research assistant (VKT) using Research Electronic Data Capture (REDCap) software (Harris et al., 2009). For each study, the following study details were extracted: authors, publication date, title, study type (i.e. primary or review article), study location (i.e. continent[s]; not mutually exclusive); and population type (i.e. typically developing, including at-risk; clinical; clinical and control). Additionally, the standardized neurodevelopmental assessment measure(s) included in each study were extracted, as well as the target age(s) at which each unique measure was utilized within the 0–6 years developmental period (i.e. < 1, 1, 2, 3, 4, 5, 6 years, or age not available [NA] but confirmed 0–6 years; not mutually exclusive). The target age(s) at which each unique measure was utilized was determined based on the age range specified within the study per measure. If an age range was not specified, an age range was computed using the mean (± 2 standard deviations [SD]) or median (± interquartile range [IQR]) age information, if specified. If the SD or IQR were not specified, the mean or median ages were considered the only target ages, to be conservative in our representation of the data. For some studies with clinical populations, only 'age at diagnosis' and 'time since diagnosis at assessment' values were provided. In such instances, the age at the time of assessment was computed based on these values (i.e. age at assessment = age at diagnosis + time since diagnosis at assessment). If a target age range was not available for a specific measure, and the age range could not be confirmed to be within the 0–6 years period, the measure was not included; if this was the case for all measures outlined in an article, the article was excluded, in adherence with our pre-specified inclusion/exclusion criteria.

Data Analysis and Synthesis

Analyses consisted of descriptive statistics of study information, including study type, population type, and study location. Categorical data were reported as proportions. The data were synthesized in various ways to capture the landscape of the literature, including target neurodevelopmental domains

that have been assessed across the target developmental period (0–6 years). The data were further synthesized for application to clinical practice by establishing a repository of domain-specific neurodevelopmental measures that have been utilized in the literature during this period, as well as a preliminary conceptual framework for cross-domain neurodevelopmental assessments during this period. All data analyses and syntheses were conducted using STATA-14/SE (StataCorp). Given the breadth-based, comprehensive, and descriptive approach taken throughout this review, in-depth considerations (e.g. meta-analytic approaches, article quality review, consensus guidelines) were outside the scope of our evaluation due to the preliminary nature of this work and limited feasibility alongside the large study size.

Neurodevelopmental Domains by Age of Assessment

The first author (BCB) reviewed all the standardized neurodevelopmental assessment measures extracted from the target articles and determined which neurodevelopmental domain(s) each measure assessed. Overarching neurodevelopmental domains (e.g. neurodevelopment, neuropsychology) were assigned for broadband measures that spanned several distinct sub-domains and were considered across a spectrum given a high degree of conceptual and nomenclatural overlap. Some domains were assigned an overarching classification to enable heightened conceptual understanding, despite individual measures not being assigned to these overarching classifications themselves (e.g. 'physical' and 'clinical' classifications). These classifications were based on information available from test publishers and developers in online documentation and/or published articles. As such, this process was descriptive in nature and classification-based, including minimal interpretation around domains. This information was determined by the author rather than extracted from the studies given that the studies inconsistently and differentially reported which neurodevelopmental domains were examined by each measure given much nomenclature overlap, differing study objectives, and differing perspectives within different fields of study (e.g. the same measure could be identified as examining two different, but related, neurodevelopmental domains across different studies). Given the overarching objective to capture neurodevelopmental assessment measures available for use across early childhood, as well as target neurodevelopmental domains, this method of data synthesis, although descriptive and preliminary in nature, was believed to most robustly and consistently capture the ability of existing measures utilized in the literature to examine neurodevelopmental domains across the target age range. General definitions that informed the classifications for the proposed overarching domains, sub-domains, and overarching classifications are provided in Table S3.

The total number of studies that included measures that examined each unique neurodevelopmental domain was reported. This value was not mutually exclusive across all domains as the studies often included one or more measures that examined one or more different domains. The age(s) at which each neurodevelopmental domain (i.e. based on the respective measures that examined each domain) had been evaluated in the literature was captured by determining the percentage of studies, of the total number of studies per domain, that included evaluation at each target age within the 0–6 years developmental period (i.e. < 1, 1, 2, 3, 4, 5, 6 years, NA). This value was not mutually exclusive across the target ages as many measures were utilized across a specified age range within the 0–6 years developmental period. To better display which domains were more frequently assessed at specific ages, gradient shading was used to visually demonstrate different percentage ranges (i.e. 0–20, 21–40, 41–60, 61–80, 81–100%). A descriptive overview of which overarching neurodevelopmental domains, sub-domains, and overarching classifications were highly represented in the literature across different developmental stages within the 0–6-years age range (neonatal, infancy, and toddler [~ 0–3 years]; preschool and early childhood [~ 4–6 years]) was provided.

Repository of Domain-Specific Neurodevelopmental Measures

To identify existing standardized neurodevelopmental measures that have been used across the target neurodevelopmental domains, a repository of domain-specific measures was compiled. These measures were not mutually exclusive across the neurodevelopmental domains given that measures often focused on one or more different domains. The total number and proportion of studies that included each measure was reported.

Conceptual Framework for Cross-Domain Neurodevelopmental Assessments

Based on the synthesized data related to neurodevelopmental domains across various measures and ages at assessment, a preliminary conceptual framework was proposed from a neuropsychological lens to highlight the interconnectedness and overlapping nature of the domains (and related nomenclature) within the highly dynamic developmental progression during the 0–6 years period. This framework encompassed all individual domains which were organized within overarching neurodevelopmental domains (for broadband measures) and overarching domain classifications (for domain groupings). The conceptual framework illustrated domains more highly represented during different age

ranges within the 0–6 developmental period (i.e. 0–3, 3–5, 5–6 years) from left to right.

Results

Study Selection

The database searches returned a total of 1194 records, of which 12 were deleted as duplicates. Following title and abstract screening, 920 records were accepted for full-text review, while 262 were excluded as they did not meet inclusion criteria. At the full-text review stage, records were excluded for the pre-specified exclusion criteria: (1) no neurodevelopmental assessment measure ($n=47$), (2) unstandardized neurodevelopmental assessment measure ($n=7$), (3) assessment measure not specified or vague ($n=15$), (4) sample above age 6 years at time of assessment ($n=31$), (5) age at assessment not specified or able to be computed ($n=1$), (6) review article with target age for assessment measure(s) not specified ($n=21$), and (7) not in full-text article form or full-text article not available ($n=3$). A total of 795 articles were identified for inclusion in the systematic review for data extraction and synthesis (see Fig. 1).

Study Characteristics

This study spanned primary ($n=755$) and review ($n=40$) articles from 1978 to 2020 (search end date). Study locations spanned Asia ($n=89$), Africa ($n=46$), Europe ($n=220$), North America ($n=259$), South America ($n=35$), and Oceania ($n=59$) (not mutually exclusive). Primary articles included typically developing (35%), clinical (42%), and clinical/control (23%) samples. All study identifiers, including authors, publication dates, and titles, are included in the supplementary material (Table S4).

Data Synthesis

Neurodevelopmental Domains by Age of Assessment

Across all the standardized neurodevelopmental assessment measures used within the target studies across the 0–6 years developmental period, a total of 33 neurodevelopmental

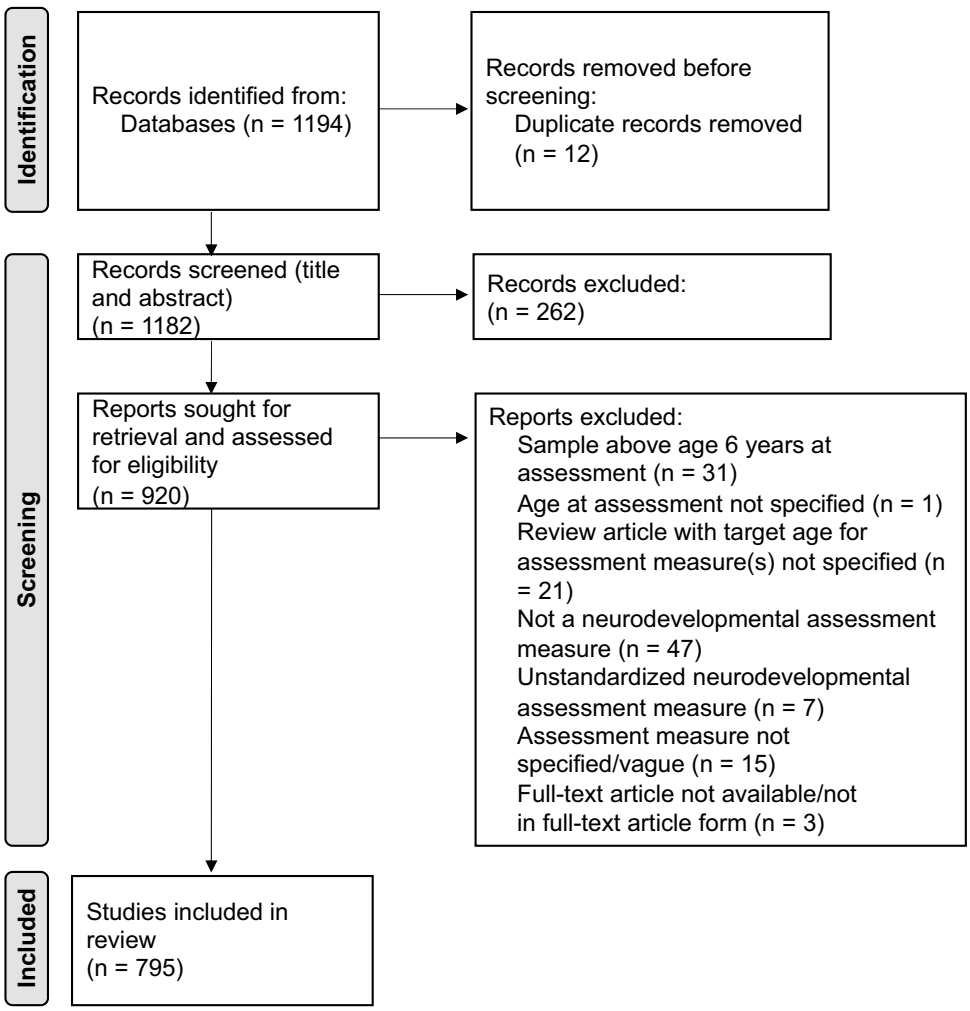

Fig. 1 PRISMA flow diagram depicting how articles were selected for review

domains were identified, of which, 6 were considered overarching neurodevelopmental domains (i.e. representing broadband measures that spanned numerous distinct sub-domains, e.g. neurodevelopment) (Fig. 2). Additionally, two overarching classifications were assigned to various related domains (i.e. 'physical' and 'clinical'

Fig. 2 PRISMA flow diagram depicting how articles were selected for review

Neurodevelopmental Domain	Total Studies (N=795)[c]	Age Assessed in the Literature (years)							
		<1	1	2	3	4	5	6	N/A[d]
		Percent of Studies (%)[c,e]							
Neurological[a]	72	50	28	32	36	43	47	40	11
Neurobehavioural[a]	11	64	0	0	0	0	0	9	27
Developmental[a]	309	34	61	59	39	22	20	13	13
Neurodevelopmental[a]	70	0	1	6	20	44	60	60	19
Neuropsychological[a]	52	2	6	19	31	38	54	67	23
Motor	150	27	23	15	19	30	43	39	19
Sensory	5	20	20	80	60	80	80	80	0
Behaviour	127	27	8	15	30	36	47	41	13
Social-Emotional	194	13	23	30	35	46	51	46	18
Adaptive Functioning	99	22	38	45	48	55	54	46	20
Relationships	9	22	67	56	44	33	33	22	11
Health-Related Quality of Life	13	8	8	31	54	69	85	92	8
Cognition	344	2	3	10	20	39	53	55	26
Language & Communication	151	7	17	26	25	38	50	42	20
Pre-Academics & Academics	77	1	1	4	14	29	42	49	32
Validity	4	0	0	0	0	25	50	50	50
Visual Perception	16	0	0	0	19	31	75	81	13
Visuomotor Integration	60	2	7	15	22	43	48	48	23
Visuospatial Integration	24	0	0	0	8	21	25	50	29
Attention	97	1	2	3	13	35	60	65	21
Executive Functioning	132	0	1	11	30	49	61	52	18
Learning & Memory	93	1	2	2	6	18	49	63	29
Psychiatric	28	0	4	7	18	32	61	54	29
Physical[b]									
Pain	2	0	50	0	0	50	0	50	0
Sleep	6	0	17	0	0	0	33	50	33
Fatigue	4	0	0	25	25	50	75	0	0
Clinical[b]									
Fetal Alcohol Spectrum Disorder	1	0	0	0	0	0	0	100	0
Autism Spectrum Disorder	65	9	38	42	49	46	54	43	22
Multiple Sclerosis	1	0	0	0	0	0	100	100	0
Stroke	3	0	33	33	33	33	33	67	33
Epilepsy	4	0	0	25	25	25	50	50	50
Concussion	8	0	0	13	13	13	0	88	0
Disability	9	22	33	44	44	44	56	56	33

[a]Overarching categories for broadband measures that span numerous domains
[b]Domains assigned an overarching classification for conceptual understanding; measures not assigned to these classifications
[c]Not mutually exclusive
[d]N/A=Not Available; age was not specified for the measure within the target domain, although the study sample was within the 0-6 years age inclusion criteria
[e]Shading visually demonstrates percentage ranges:

0-20	21-40	41-60	61-80	81-100

classifications). The total number of studies that included measures that examined each overarching or unique neurodevelopmental domain was reported (i.e. range of 1–344; not mutually exclusive across domains).

Of the total number of studies per domain, the percentage of studies that included evaluation of each neurodevelopmental domain at each target age within the 0–6 years developmental period (i.e. < 1, 1, 2, 3, 4, 5, 6 years, NA) was reported (i.e. range of 0–100%; not mutually exclusive across the target ages). Gradient shading of these percentage ranges (i.e. 0–20, 21–40, 41–60, 61–80, 81–100%) broadly indicated that, consistent with our hypotheses, most of the literature to date involving neurodevelopmental assessments in the 0–6 years developmental period has involved older children within the preschool age range (~ 4–6 years). More specifically, during neonatal, infancy, and toddler periods (~ 0–3 years), most measures encompassed overarching neurological, neurobehavioural, and developmental domains (across a spectrum), as well as related sub-domains of memory, sensory, behaviour, social-emotional, adaptive functioning, and relationships. It was not until preschool and early childhood periods (~ 4–6 years) that more comprehensive evaluations of overarching neurodevelopmental, neuropsychological, and psychiatric domains (across a spectrum) occurred, with related focus on domains of cognition, language, academics, attention, executive functioning, and memory. Moreover, our conceptual framework was proposed in order to visually and conceptually illustrate the patterns gleaned from the literature synthesized in Fig. 2 regarding which overarching neurodevelopmental domains, sub-domains, and overarching classifications were highly represented across different developmental stages within the 0–6-years age range.

Repository of Domain-Specific Neurodevelopmental Measures

Across all included studies, a total of 607 unique standardized neurodevelopmental assessment measures were identified for the 0–6 years developmental period. A repository of domain-specific measures was compiled, as shown in the supplementary material (Table S5; not mutually exclusive across domains). The total number and proportion of studies that included each measure was reported to illustrate the frequency of use in the literature to date.

Conceptual Framework for Cross-Domain Neurodevelopmental Assessments

A preliminary conceptual framework was proposed to highlight the neurodevelopmental domains relevant to assessments undertaken in the literature across the 0–6 years developmental period (Fig. 3). This illustrated the interconnectedness and overlapping nature of the domains, especially given the dynamic nature of development during the early childhood period. The six overarching neurodevelopmental domains (for broadband measures), namely neurological, neurobehavioural, developmental, neurodevelopmental, neuropsychological, and psychiatric domains, were illustrated across a spectrum wherein they were not considered distinct but rather fluid in their progression and overlap across the 0–6 years period. A spectrum was necessitated given that there was much nomenclatural and conceptual overlap across the domains, with additional complexity represented in the domains as developmental capacities progress with age. Through this conceptual framework, we strove to visually and conceptually illustrate the patterns gleaned from the literature synthesized in Fig. 2 regarding which overarching neurodevelopmental domains, sub-domains, and overarching classifications were highly represented across different developmental stages within the 0–6-years age range.

To highlight the initial capacities typically assessed during the neonatal, infancy, and toddler periods (~ 0–3 years), the overarching neurological domain was shown to overlap with the overarching neurobehavioural domain, largely encompassing motor and sensory abilities, as well as behavioural capacities. As development progresses into the toddler and preschool periods (~ 3–5 years), more robust evaluation of development was seen to occur, as represented by the overarching developmental and neurodevelopmental domains which were highly overlapping in nature, encompassing various behavioural skills (thus overlapping with the overarching neurobehavioural domain as well) in addition to social-emotional, adaptive functioning, and relational capacities integral to early development. Within the overarching developmental and neurodevelopmental domains, early evaluation of cognition, language acquisition, and preacademic skills were observed, as typical for early developmental assessments.

As development progresses into the preschool and early childhood periods (~ 5–6 years), more comprehensive assessments are feasible across differing capacities. Therefore, the existing overarching developmental and neurodevelopmental domains were encapsulated within neuropsychological evaluation more broadly, which often encompasses more complex capacities (i.e. attention, executive functioning, learning and memory, visual perception, visuomotor integration, visuospatial integration) that build upon foundational developmental and neurodevelopmental skills. This illustration represents the shift from early developmental assessments to more robust neuropsychological assessments encompassing differing domains that is possible in the later early childhood years. As such, validity testing was illustrated to be relevant during this time as developmental skills become more complex. The overarching psychiatric domain is distinct from the overlapping developmental, neurodevelopmental, and

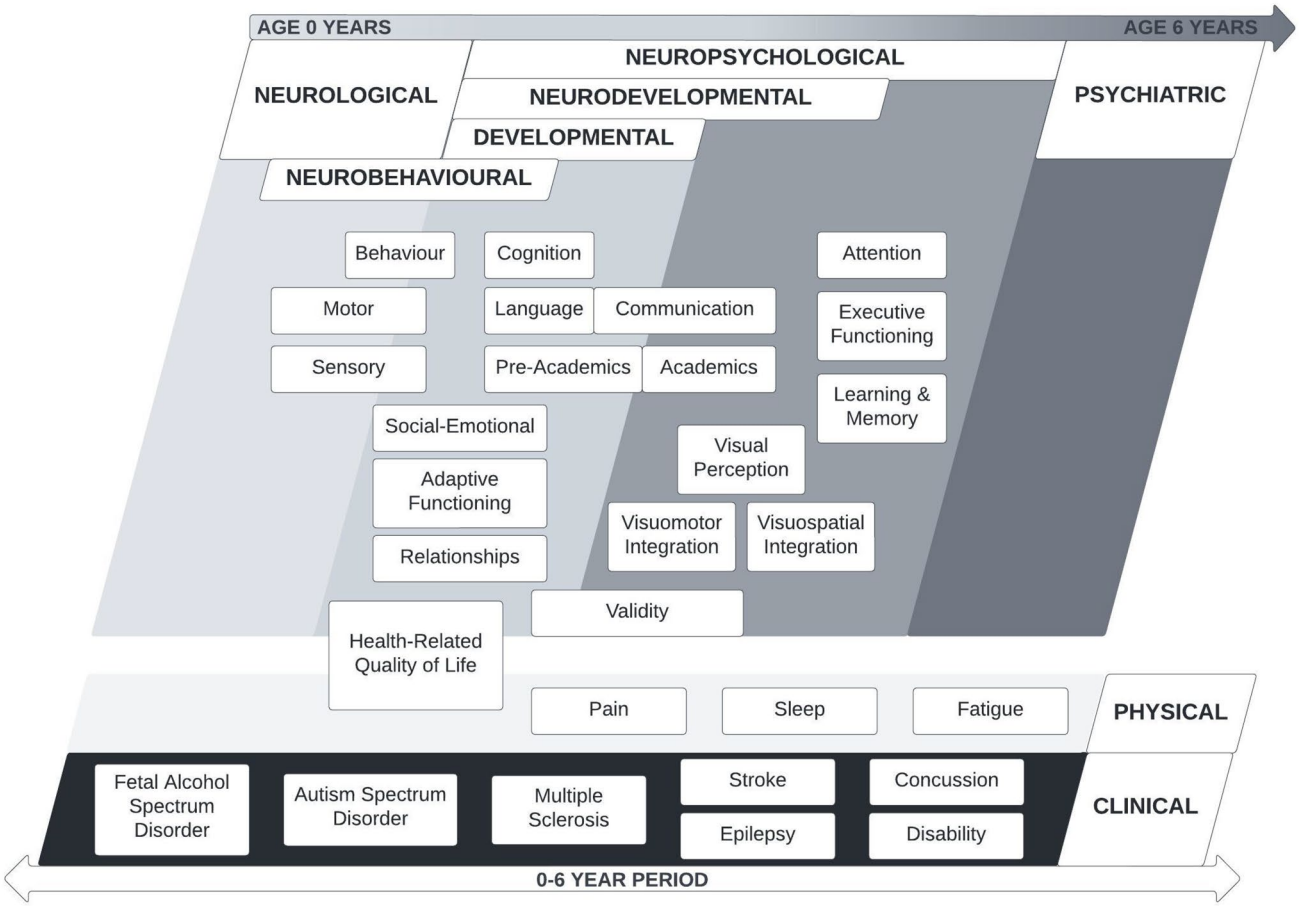

Fig. 3 Conceptual framework for cross-domain neurodevelopmental assessments in infancy and early childhood. This preliminary conceptual framework illustrates overarching neurodevelopmental domains (capital text) and conceptually related sub-domains (lowercase text) that were highly represented across different developmental stages within the 0–6-years age range across a spectrum (top portion). Likewise, two overarching classifications (capital text) that spanned the full 0–6-years age range were assigned to relevant sub-domains (lowercase text) to enable conceptual understanding (bottom portion)

neuropsychological domains because it encompasses the onset of acute mental health and psychiatric concerns in the early childhood period (~ 5–6 years), which become more pronounced with development across the lifespan.

Overall, the overarching neurological, neurobehavioural, developmental, neurodevelopmental, neuropsychological, and psychiatric domains represented a spectrum of overarching domains with nomenclatural and conceptual overlap across a period of dynamic development from 0–6 years. Other overarching classifications were identified as distinct from that spectrum of domains and also spanned across the entirety of the 0–6 years period. Namely, the physical health classification included health-related quality of life (with some overlap with the developmental/neurodevelopmental domains), pain, sleep, and fatigue domains that were often assessed across the 0–6 years period. Additionally, some measures were related to specific clinical conditions (i.e. clinical classification) relevant across all of early childhood, including fetal alcohol spectrum disorder, autism spectrum disorder, multiple sclerosis, stroke, epilepsy, concussion, and disabilities more broadly. Although other clinical conditions may impact neurodevelopment during the 0–6-years period, those highlighted within our conceptual framework represent conditions with condition-specific measures utilized in the literature to date. Taken together, the proposed conceptual framework portrays how varying neurodevelopmental domains derived from this review, as well as the pattern of findings within and across the 0–6 years period, can be conceptualized.

Discussion

This study comprises the first known systematic review in the field of infant and early childhood neurodevelopment, including 795 articles from 1978 to 2020 with international representation. The purpose of this review was to (1) identify neurodevelopmental assessment measures used across infancy and early childhood, (2) compile a repository of

domain-specific neurodevelopmental assessment measures, and (3) establish a preliminary conceptual framework for cross-domain neurodevelopmental assessments across infancy and early childhood. Through this discussion, we outline clinical recommendations and next steps for the field of infant and early childhood neurodevelopmental assessments. Taken together, this review contributes preliminary understanding around assessment measures, domains, and a preliminary framework for the assessment of infants and young children to help advance assessment methods for the evaluation of early neurodevelopmental profiles. Early assessments can inform prevention and early interventions which, together, can harness the neuroplasticity and dynamic development that is unique to the 0–6 years developmental period to maximize neurodevelopmental outcomes. In conducting this review, we hoped that it would serve as a catalyst for the field of infant and early childhood neurodevelopment and provide a foundation for future research and clinical guidelines to inform early and comprehensive neurodevelopmental assessment methods.

Neurodevelopmental Domains by Age of Assessment

Within this review, we found an increase in the number of papers focused on neurodevelopmental assessment measures as age progressed across the 0–6 years developmental period. To date, most of the literature has involved older children within the preschool age range (~ 4–6 years), with minimal coverage of the neonatal, infancy, and toddler periods (~ 0–3 years). Given the limited resources allocated to the advancement of early neurodevelopmental assessment methods and preventative care (Baron & Anderson, 2012; Baron & Leonberger, 2012; Brito et al., 2019), most children are not assessed until school-age (Heffelfinger & Koop, 2009; McCain, 2020). Despite some increases in the empirical evaluation of neurodevelopmental assessment measures within the preschool period, this does not necessarily correspond with an increase in frequency of preschool neurodevelopmental assessments clinically. Future research should explore patterns of clinical assessments within this age range to better understand whether the paucity of literature aligns, as suspected, with the nature of clinical work.

Across all the standardized neurodevelopmental assessment measures being used within the 0–6 years developmental period empirically, 33 neurodevelopmental domains were identified. However, these domains were not equally represented across the various developmental stages. During neonatal, infancy, and toddler periods (~ 0–3 years), most measures were found to encompass the overarching neurological (including related motor and sensory sub-domains), neurobehavioural (including related behaviour sub-domain), and developmental (including related social-emotional, adaptive functioning, and relationship sub-domains) domains, with general classifications informed by our conceptual framework. Despite the use of differing nomenclature, this conceptual organization is consistent with formative literature on neuropsychological functions assessed in this age range as typically encompassing basic neurological functions, mental activity, and sensorimotor (visual-motor integration, fine-motor, gross-motor) abilities (Aylward, 1988, 1997b). This conceptual organization also highlights the ability for early assessments to capture basic formative developmental capacities, contrary to existing misconceptions that assessments cannot occur in the neonatal, infancy, and toddler periods.

Across our review, and informed again by our proposed framework, increasingly comprehensive evaluations of overarching neurodevelopmental (including related cognition, language, and academic sub-domains), neuropsychological (including related attention, executive functioning, and memory sub-domains), and psychiatric domains emerged across the preschool and early childhood periods (~ 4–6 years). This trend is in keeping with formative literature which noted a shift away from neurological functions and mental activity during this period, with the emphasis instead placed on higher-level receptive (e.g. visual-perceptual, language, spatial relations), expressive (e.g. language, fine-motor constructional, visual-spatial orientation, coordination), and processing (e.g. attention, cognition) abilities (Aylward, 1988, 1997b). The increase in developmental abilities that can be assessed aligns with the heightened complexity of capacities that emerge with age given the increase in structural and functional brain development, as well as the strong environmental and relational impacts on these capacities with age (Bullins et al., 2016; Galván, 2010; Gao et al., 2013).

Repository of Domain-Specific Neurodevelopmental Measures

Another main limitation that has hindered the advancement of neurodevelopmental assessment work in early childhood is the absence of standardized, developmentally suitable, psychological instruments (Aylward, 1997b, 2004a; Baron, 2017; Baron & Anderson, 2012; Bracken, 1987; Heffelfinger & Koop, 2009; Mrakotsky & Heffelfinger, 2006; Nagle, 2004). Nonetheless, over the course of this review, we compiled existing standardized neurodevelopmental measures that have been used empirically over the 0–6 years period into a comprehensive repository of measures that spanned 33 neurodevelopmental domains. These findings highlight the extensive measures available across various domains for use in this age range, likewise illustrating the differential frequency of use of each measure in the literature. This is

consistent with literature highlighting advancements in the field, namely related to the increase in assessment instruments available for young children across capacities of differing complexity (Baron & Leonberger, 2012; Heffelfinger & Koop, 2009). As such, the true limitation that is hindering advancement of this field is a lack of understanding and clinical guidelines around *which measures* to use, to assess *which domains*, at *which age ranges*. Moreover, existing classification schemas and theoretical frameworks for the assessment of young children are limited as they do not provide guidance around which neurodevelopmental assessment measures to use to assess specific capacities. Therefore, the repository we have compiled is novel in that, in addition to being the first of its kind and encompassing a large body of empirical research, it informs and aligns with our proposed cross-domain conceptual framework.

In light of the lack of existing systematic reviews on this topic to date, we endeavoured to capture the breadth of knowledge in this field through this comprehensive review and repository. However, future research is needed to take a depth-based approach and to begin examining the psychometric properties (i.e. reliability and validity) and normative data available specific to these measures, from a clinical perspective. The expectation is that this work, which was shaped by empirical findings, can contribute to the establishment of clinical guidelines to inform which measures should be used clinically to assess specific domains for target age ranges within the highly dynamic 0–6 years period.

Conceptual Framework for Cross-Domain Neurodevelopmental Assessments

As noted, the field of infant and early childhood neurodevelopment has been limited by the lack of a conceptual framework to guide assessment methods and best practice recommendations (i.e. outlining target functional abilities/domains to be assessed at different ages with corresponding measures) (Aylward, 1988, 1997b; Mrakotsky & Heffelfinger, 2006). Based on this review, we proposed a preliminary conceptual framework for cross-domain neurodevelopmental assessments which incorporated the 33 neurodevelopmental domains that were identified across the standardized neurodevelopmental assessment measures used in research across the 0–6 years period. This framework was proposed from a neuropsychological lens to highlight the interconnected and overlapping nature of various functional domains. This complexity is consistent with Aylward's (1988) description of the high degree of overlap suspected to occur between functional abilities across the dynamic 0–6 years developmental period.

Given repeated calls to action for the development of a formalized conceptual framework in this field (Aylward, 1988, 1997b; Mrakotsky & Heffelfinger, 2006), some researchers attempted to formalize classification schemas decades ago. In their seminal work, Aylward (1988) proposed a high-level classification schema for early neuropsychological assessments which was a synthesis of several previous classifications for school-age children (Levine, 1983; Lezak, 1983) with applicability extrapolated to the neonatal and early childhood periods. The classification schema included five conceptual clusters, namely (1) basic neurological functions/intactness, (2) receptive functions, (3) expressive functions, (4) processing, and (5) mental activity, with various distinct functional abilities included within each cluster (Aylward, 1988). This formative classification schema sparked preliminary discourse regarding differing developmental clusters that can be measured across different developmental stages within the 0–6 years period (e.g. newborn, infant, toddler/early childhood) (Aylward, 1988, 1997b). It also contributed to the development of seminal early neurodevelopmental scales (e.g. Early Neuropsychological Optimality Rating Scale; Bayley Infant Neurodevelopment Screener).

Over recent decades, however, this classification schema has not been adopted as a conceptual framework upon which clinical guidelines could be built given numerous limitations. Firstly, there was a high degree of overlap noted between the five conceptual clusters across the various developmental stages within the 0–6 years period (e.g. newborn, infant, toddler/early childhood), because various clusters were noted to be 'primarily' involved at various stages, while the other clusters were noted to still have 'secondary' or 'tertiary' involvement (Aylward, 1988, 1997b). Likewise, in contrast with our conceptual framework, the high-level nature of the proposed clusters in this classification schema included clusters which encompassed several highly distinct functional abilities (e.g. fine-motor, language, coordination), some of which were not applicable at each developmental stage in the same manner but were indistinguishable given this high-level schematic classification. In addition to not specifying which abilities could be assessed explicitly at each age, these clusters were not aligned with standardized neurodevelopmental assessment measures that could be utilized to assess specific abilities. In contrast, our conceptual framework is uniquely linked with the provided repository of existing standardized neurodevelopmental measures that have been used empirically over the 0–6 years period, with alignment across target domains.

Despite the lack of a conceptual framework to guide early neurodevelopmental assessments, progress has been made regarding theoretical tenets to incorporate into neuropsychological assessments with children (Mrakotsky & Heffelfinger, 2006). Fletcher and Taylor (1984) proposed the 'functional organization approach', a normative developmental approach wherein the child's cognitive ability is structured at the core of the assessment, with emphasis placed on how deficits

interfere with normal development rather than identifying areas of deficit. This approach emphasized the importance of processes of change and integrated different variables underlying development, including brain-related and context-specific factors. This approach was important in moving beyond static neuropsychological models for adulthood and toward a more developmental perspective necessitated in childhood (Mrakotsky & Heffelfinger, 2006). Nonetheless, normative developmental approaches were critiqued for their focus on the child's cognitive ability in the here and now, rather than viewing the child as a whole (Bernstein, 2000). In response, Bernstein and colleagues (Bernstein, 2000; Holmes-Bernstein & Waber, 1990) proposed the 'neurodevelopmental systems approach' wherein the child was placed at the core of the assessment, incorporating developmental and neuropsychological theory to consider past development and neurological, medical, and family factors. This highlighted a comprehensive and holistic approach to assessments wherein information was integrated from several sources (history, observation, test performance) to yield a wealth of clinical data for preschool-aged children when few standardized assessment measures were thought to be available (Mrakotsky & Heffelfinger, 2006).

This emphasis on brain, context, and developmental interactions built the framework of the 'systems approach' in neuropsychological assessment wherein the brain is seen as the major, although not exclusive, substrate for learning and behaviour (Bernstein, 2000; Holmes-Bernstein & Waber, 1990). As such, the importance of considering neural systems underlying brain functions (i.e. when and how systems develop) was noted, including localization of functions and behavioural output in the case of insult to a brain region (Mrakotsky & Heffelfinger, 2006). This framework extended into the 'developmental systems approach' wherein the importance of context is emphasized given that the brain does not operate or develop in isolation but rather in constant interaction with the environment (Bronfenbrenner, 2005; Bronfenbrenner & Ceci, 1994; Greenough et al., 1987). Taken together, these theoretical advancements highlight the importance of comprehensive assessments in early childhood wherein it is necessary to understand *what* is developing *when*, in addition to *how*, and in *what context* (Mrakotsky & Heffelfinger, 2006).

Nonetheless, this theoretical progress has occurred in the absence of advancement with respect to a conceptual framework to tangibly inform assessment methods and standards of care for young children. The historical theoretical progress aligns with our proposed conceptual framework given that it is comprehensive and holistic in nature, including coverage across the dynamic 0–6-years development period which recognizes the differential developmental context and influence of injury across this sensitive period. Likewise, our framework includes coverage of environmental and contextual factors via various overarching neurodevelopmental domains, sub-domains, and overarching classifications (e.g. relationships, social-emotional, adaptive functioning, health-related quality of life domains; physical and clinical overarching classifications) and the inclusion of measures spanning various respondents (e.g. caregiver, teacher report measures). We hope that our work, including our proposed conceptual framework, alongside existing theoretical advancements, will spearhead tangible discussions about how clinical assessments for young children can be implemented to inform practice guidelines.

Clinical Recommendations

The early developmental period is a window of opportunity for prevention and early intervention supports to harness neuroplasticity and maximize neurodevelopmental trajectories across the lifespan. More specifically, neuroplasticity reflects the capacity for adaptive change in response to environmental stimuli and experiential enrichment via modification of neural circuitry in the context of healthy development (Anderson et al., 2011; Galván, 2010). The greatest period of neuroplasticity is within the first few years of life when more than a million new neural connections form every second (Centre on the Developing Child, 2008). With respect to early brain insult populations, as is highly relevant to pediatric neuropsychological assessment, neuroplasticity is more complex given competing theoretical perspectives of 'early plasticity' (greater flexibility of the immature brain, and associated good recovery and outcome) and 'early vulnerability' (young brain's unique susceptibility and subsequent poor recovery and outcome) which are thought to exist across a recovery continuum (Anderson et al., 2011; Chugani et al., 1996). Nonetheless, consideration of the highly dynamic changes that can occur across the early developmental years is essential from a brain-behaviour relationship perspective and in considering how assessments can inform early identification and prevention methods given flexibility and malleability.

Early neurodevelopmental assessments thus have numerous clinical applications. Specifically, advancement in this field related to early assessment methods can help determine the early neurodevelopmental status of infants and young children, identify children who would benefit from early intervention supports, evaluate outcomes post medical procedures/interventions, document changes in neurodevelopmental status over time, predict later levels of functioning and prognoses, and yield information about early brain-behaviour relationships (Aylward, 1988, 1997b). Likewise, there are clear cost-benefits of early investments in child development as they can ameliorate neurodevelopmental risks and reduce the need for future

services. More specifically, the earlier the investment in early childhood development, the greater the return on investment for economic and workforce development, with differences seen even within the 0–6 years period such that early interventions must occur as early as possible (Heckman, 2012). The societal and economic benefits of contributing toward early development and care have been shown to be associated with a 7–10% per year return on investment on increased school and career achievement, as well as reduced costs in remedial education, health, and criminal justice system expenditures (Council of Economic Advisers, 2015; Heckman, 2012). Nonetheless, the cost of stagnancy is high as, globally, over 53 million children under the age of 5 years have developmental disabilities, with profound lifelong consequence noted (Olusanya et al., 2022), highlighting a clear need for clinical change.

Taken together, findings from this review, and from broader recommendations within the field, point to a need for comprehensive assessment procedures and clinical care guidelines which outline assessment measures and target neurodevelopmental domains to be evaluated at key developmental stages within the 0–6 years period. This work must occur from a developmental psychological and neuropsychological lens given the specialized understanding of early child development, environmental and systemic factors that impact development, and the neurological and neurodevelopmental underpinnings of development, including injury to the developing brain. A shift toward prevention and early intervention models of care is essential to advance opportunities for all children and maximize neurodevelopmental trajectories and quality of life across the lifespan. It is thus recommended that early neurodevelopmental assessments occur for children who have experienced early risk factors, injury, or adversities, as well as those who demonstrate early delays. These assessments should occur as early as possible within the early developmental period and before entry into school.

Strengths, Limitations, and Future Directions

This systematic review encompassed a comprehensive overview of the literature on neurodevelopmental assessments undertaken with infants and young children, an area where there has been limited previous research to date. This review captured the breadth of knowledge in this field, spanning 795 articles with strong historical, geographical, and empirical representation. A total of 33 neurodevelopmental domains were identified, with numerous neurodevelopmental assessment measures specified for use within each of the 33 domains. In addition to illustrating general trends in the literature related to assessment measures across neurodevelopmental domains and age ranges, this work informed a repository of assessment measures and a preliminary conceptual framework for future clinical and research use.

Nonetheless, given the emphasis placed on breadth throughout this review, in-depth considerations were outside the scope of our evaluation due to limited feasibility alongside a large sample of articles. As such, we took a breadth-based, comprehensive, and descriptive approach because we were not able to evaluate the quality of each article or use meta-analytic approaches. We were also not able to review the psychometric properties of the assessment measures, nor their clinical utility with specific ages within the 0–6 years period clinically. Rather, we focused our attention on describing the ages at which certain measures had been used to study specific neurodevelopmental domains to inform a repository of measures and preliminary conceptual framework.

Our proposed framework is limited given that domain classifications for each measure were assigned by a single reviewer rather than across multiple reviewers with discrepancies adjudicated. This approach was taken given the need for uniformity in establishing a domain classification system that could organize the expansive results in a meaningful manner across the age ranges, into an organized repository, and into a conceptual framework across an extensive number of measures. Nonetheless, given the preliminary nature of our proposed framework, it does not provide clinical consensus guidelines around target domains and related assessment measures for use across the 0–6-years period. Rather our preliminary framework describes the landscape of the literature to inform this necessary future work. Although we discussed different ways in which the proposed conceptual framework can be uniquely interpreted at specific developmental stages within the 0–6 years period (neonatal/infancy/toddler, preschool/early childhood), this model is intended to represent the entirety of the 0–6 years period. As such, future work will be needed to differentiate which neurodevelopmental domains are essential for inclusion in assessments at each developmental stage, with care taken to reach consensus across the field of infant and early childhood neuropsychology with respect to domain nomenclature and selection given the current ambiguity in the literature. Notably, future research and clinical work must prioritize the establishment of consensus guidelines around target domains and measures for use with the infancy and early childhood populations, including differentiation across key developmental stages within the 0–6-years period, as well as further differentiation of sub-domains within the proposed domains (e.g. fine-motor and gross-motor within motor). Moreover, it will be necessary to reconceptualize the role of neuropsychology across the 0–6-years developmental period as assessments, especially in the early years,

may not fit the mold of more typical neuropsychological evaluations at school-age which span higher-level cognitive domains (e.g. memory, executive functioning). This highlights a need for flexibility in the field as neuropsychological expertise regarding brain-behaviour relationships and child development intersect to allow unique and innovative models of care in the early years. In all, our conceptual framework is preliminary and represents the initial stage of a long program of research that will require clarity and consensus across professionals in the field, as well as future studies with international representation and more complex statistical analyses.

Taken together, we believe this review has set the foundation upon which future research can begin to inform the establishment of clinical consensus guidelines for comprehensive neurodevelopmental assessments that are unique to specific ages within the 0–6 years period in light of dynamic development and differentially appropriate target domains during this time. Long-term, as clinical care begins to include early neurodevelopmental assessments, we expect that researchers will be able to investigate the impact of early assessments in infancy and early childhood on longitudinal neurodevelopmental trajectories, quality of life, and well-being. This research could focus on the potentially mediating role of early intervention facilitated through early assessments.

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Declarations

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