Journal of Environmental Psychology 114 (2026) 103167

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.sciencedirect.com/journal/journal-of-environmental-psychology

Perceptual and emotional responses to home built environments among preschool children with physical mobility impairments: A scoping review

Zhouyan He [a,*], Luoqiuzi Fu [b], Luca Guardigli [a]

[a] Department of Architecture, University of Bologna, Viale del Risorgimento 2, Bologna, 40136, Italy
[b] Faculty of Fine Arts, University of Lisbon, Largo da Academia Nacional de Belas Artes 4, Lisboa, 1249-058, Portugal

ARTICLE INFO

Keywords:
Preschool children
Physical mobility impairments
Home environment
Spatial behavior
Emotional response
Scoping review

ABSTRACT

Preschool children with physical mobility impairments as a form of disabilities (PMIOD) may face concurrent challenges in perceptual behavior, spatial participation, and emotional responses in home and everyday environments. This study conducted a scoping review. Search terms and eligibility criteria were developed based on the Population–Concept–Context framework, and the review was reported following PRISMA-ScR. Searches were conducted in Scopus, Web of Science, PubMed, and APA PsycINFO/APA PsycArticles for articles and reviews published between January 2015 and May 2026. A total of 1871 records were identified. After deduplication, 1589 titles and abstracts were screened, 654 full texts were assessed, and 176 studies were finally included. The findings showed that mobility limitations in PMIOD children were associated with reduced spatial exploration, difficulties in mobility, obstacle avoidance, and environmental understanding, restricted play participation, and limited action autonomy. Spatial accessibility, path continuity, assistive device fit, caregiver support, and sensory environments were jointly associated with children's modes of participation and emotional experiences. Existing studies mainly used questionnaires, proxy reports, interviews, behavioral observation, video coding, sensors, and assistive technologies to assess related behavioral and emotional expressions. However, the standardization of these methods, their age appropriateness, and evidence from real home spaces remain limited. Overall, the perceptual behaviors and emotional responses of PMIOD children were jointly related to physical ability, spatial conditions, assistive devices, and caregiving relationships. Future research should further differentiate age and mobility ability differences and translate home space factors, including paths, furniture, assistive devices, and sensory environments, into measurable and comparable analytical variables.

1. Introduction

The WHO Global Disability Action Plan 2014–2021 called for barriers faced by persons with disabilities to be reduced and for rehabilitation, assistive technology, disability data, and related research to be strengthened (WHO, 2015). The 2030 Agenda for Sustainable Development subsequently proposed the principle of "Leave no one behind," emphasizing the inclusion of vulnerable groups in social development and environmental support (Stuart et al., 2016; United Nations, 2015). Within this policy context, the participation and environmental support needs of children with physical mobility impairments as a form of disability (PMIOD) represent an important concern in child development, rehabilitation, and environmental research (UNICEF, 2022; He et al., 2026; UNICEF, 2021; WHO, 2022). In this study, PMIOD is used as a working umbrella term to define children who experience limitations in limb function, postural control, or mobility during child development or functional recovery (He et al., 2026; WHO, 2007). This group may include children with formally diagnosed physical disabilities, children with developmental motor disorders, children who experience temporary functional limitations after injury, disease, surgery, or trauma, and children who have not reached the threshold of formal disability diagnosis but still experience restricted physical movement, impaired mobility, or the need for mobility support. Although the medical causes and recovery possibilities of these children may differ, these children may all face restricted spatial access, difficulties in path movement, reduced opportunities for exploration, and increased needs for assistive devices or adult support in home and everyday environments. Therefore, PMIOD is useful for discussing the integrated physiological, psychological, behavioral, and environmental support needs of children with mobility limitations (UNICEF, 2021;

* Corresponding author.
E-mail addresses: zhouyan.he2@unibo.it (Z. He), Luoqiuzifu@edu.ulisboa.pt (L. Fu), luca.Guardigli@unibo.it (L. Guardigli).

https://doi.org/10.1016/j.jenvp.2026.103167
Received 11 February 2026; Received in revised form 1 August 2026; Accepted 2 August 2026
Available online 4 August 2026
0272-4944/© 2026 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

WHO, 2022; WHO & UNICEF, 2022). Discussing PMIOD across child development, rehabilitation, environmental behavior, and inclusive design can address the limited attention given to the spatial experiences of children with mobility limitations in existing studies. It can also extend related research from clinical functional assessment to spatial participation, environmental interaction, and emotional adaptation (Wertlieb, 2019).

Children's everyday development depends strongly on family and proximal living environments. As children grow older, their developmental changes and needs vary greatly across stages. Among these stages, the preschool period, usually referring to children aged 3–6 years, is an important transition from infancy and toddlerhood to school age (Black et al., 2017; Britto et al., 2017). It is also a period in which children gradually move from the family to school and broader social environments (UNICEF, 2017, 2019). This stage is important for physical development, cognitive development, emotion regulation, and social participation (Black et al., 2017; Kesiktas et al., 2009; Institute of Medicine & National Research Council, 2000). For PMIOD children, home and everyday environments are not only basic living settings but also important contexts for spatial exploration, physical activity, emotional expression, and social interaction (Albrecht & Khetani, 2017; Anaby et al., 2014; Barchus et al., 2023; Khetani et al., 2015; Law et al., 2013). From the perspective of child environment interaction, the development and participation of PMIOD children are jointly influenced by individual mobility ability, caregiving support, assistive devices, and environmental accessibility. Therefore, home environments and spatial conditions have a sustained influence on the development of preschool PMIOD children (Albrecht & Khetani, 2017; Anaby et al., 2014; Celik Turan et al., 2025; Di Marino et al., 2018; Hwang et al., 2014).

Research on home spaces and everyday environments for PMIOD children aged 3–6 involves multiple fields, including architectural design, child development, rehabilitation therapy, assistive technology, and environmental psychology (Di Marino et al., 2018; Imms et al., 2017; WHO, 2007; Yu et al., 2024). Children at this stage are in a period of rapid development, and their muscle coordination, balance, spatial mobility, emotional expression, and need for autonomy are still developing (Adolph & Hoch, 2019; Haywood & Getchell, 2021; Lilian et al., 2016; Ungureanu, 2013). For PMIOD children, these developmental characteristics are further influenced by physical function, postural control, assistive devices, and the need for adult assistance (Anderson et al., 2013; Farran et al., 2021; Livingstone & Paleg, 2014; Ungureanu, 2013). In spatial settings, PMIOD children may show fewer opportunities for active crawling, approaching objects, grasping furniture, changing direction, and autonomous exploration. PMIOD children may also rely more on parents or caregivers to complete movement and activities (Anderson et al., 2013; Campos et al., 2000; Livingstone & Field, 2021; Oudgenoeg-Paz & Rivière, 2014). Restricted mobility may reduce children's opportunities to interact effectively with living spaces (Belmonti et al., 2015; Farran et al., 2021; Stanton et al., 1998). In this study, spatial behavior mainly refers to how PMIOD children enter spaces, move along paths, approach targets, avoid obstacles, use assistive devices, and participate in activities in home and everyday environments. Spatial conditions refer to the physical environment, assistive device fit, and caregiving support that influence these behaviors.

From the perspective of embodied spatial cognition, children's understanding of space is often gradually formed through approaching objects, changing positions, avoiding obstacles, and interacting with the environment. When children cannot actively approach objects, peers, or activity areas in the environment, their understanding of spatial paths, object locations, environmental stimuli, and social opportunities may also be affected. This may further hinder the development of spatial cognition and related skills (Farran et al., 2021; Ungureanu, 2013). In this context, children's visual attention, tactile contact, assistive device use, and adult assistance behaviors may become important clues for understanding their spatial perception and environmental participation (Huang, 2018; Livingstone & Field, 2021).

The preschool period is also an important stage in which children's emotion regulation, self-awareness, and need for autonomy gradually develop (Eisenberg et al., 2010). From the perspective of developmental environmental psychology, children's emotional responses do not arise only from their individual psychological states. These responses are also closely related to whether children can enter spaces, approach targets, participate in activities, and obtain adult and environmental support. Compared with their peers, PMIOD children may be more likely to experience frustration, anxiety, insecurity, or withdrawal from participation because of mobility limitations, activity dependence, and insufficient opportunities for environmental participation (Downs et al., 2018; McMahon et al., 2020; Sigurdardottir et al., 2010). These emotional responses should not be understood simply as individual psychological problems. Instead, these responses should be interpreted within the combined context of physical limitations, caregiving support, assistive devices, and environmental accessibility (Downs et al., 2018; Hollin et al., 2022). Therefore, PMIOD children's tactile contact, visual attention, spatial approach patterns, and environmental exploration behaviors may differ from the default user assumptions in conventional child oriented spatial design. However, these differences still need to be further discussed with reference to specific spatial contexts and behavioral evidence (Imrie, 2012; Steinfeld & Maisel, 2012; Yu et al., 2024).

Current research and design practice have begun to address the spatial and support needs of young children from the perspectives of child participation, family support, environmental factors, and product adaptation (Celik Turan et al., 2025; J. K. Kim, 2016; Yu et al., 2024). Existing reviews have also discussed related issues from the perspectives of participation measurement in childhood disability, family centered services, mental health, socioemotional development, and environmental factors (Adair et al., 2018; Almasri et al., 2018; Celik Turan et al., 2025; Downs et al., 2018; Hansen et al., 2025; Valentín-Gudiol et al., 2017). These studies provide an important basis for understanding children's participation, functional development, family support, and mental health. However, existing studies have rarely understood the everyday experiences of PMIOD children through the process of spatial action. The physical mobility limitations, spatial behaviors, emotional experiences, and home environmental fit of PMIOD children still require further investigation (Celik Turan et al., 2025; He et al., 2026). In particular, the relationships among movement paths, exploratory behaviors, assistive device use, emotional responses, and caregiver support in real home spaces remain insufficiently synthesized (Adair et al., 2018; He et al., 2026; Kesiktas et al., 2009).

In this review, child environment interaction is used as the overall conceptual framing for understanding the spatial behaviors and emotional responses of PMIOD children. Within this framing, these behaviors and responses are interpreted in relation to the interaction among individual physical ability, home and everyday environments, assistive devices, and caregiving support (Bronfenbrenner, 1979; WHO, 2007, 2022). Embodied spatial cognition helps explain how children form spatial understanding through movement, tactile contact, obstacle avoidance, and assistive device use. Developmental environmental psychology helps explain how children's emotional responses are related to spatial access, activity participation, environmental support, and adult assistance.

The 2030 Agenda for Sustainable Development gave science, technology, and innovation a clearer role in advancing social inclusion and sustainable development goals (Colglazier, 2015). Based on this policy context, the conceptual framework, and the research gaps identified above, this review used 2015, the calendar year in which the 2030 Agenda was adopted, as the temporal reference point for the evidence map (Stuart et al., 2016; United Nations, 2015). It examined studies published from January 2015 to May 2026 to trace developments in environmental participation, spatial behavior, emotional responses, and related assessment methods among PMIOD children during this period. Earlier foundational literature was retained where necessary to establish the conceptual background.

Within this scope, the review synthesizes evidence distributed across child development, rehabilitation, assistive technology, environmental behavior, and design research. It focuses on summarizing the spatial behaviors and emotional responses of PMIOD children in home and everyday environments, identifying the observation methods, measurement tools, and technology assisted assessment approaches used in existing studies, and clarifying the remaining gaps in current evidence (Arksey & O'Malley, 2005).

Guided by this framework, this study addresses the following research questions.

1) How do existing studies describe the perceptual behaviors, mobility exploration, and participation characteristics of PMIOD children aged 3–6 in environmental contexts?
2) What emotional responses do PMIOD children show during spatial interaction and everyday participation, and how are these responses related to physical limitations, caregiving support, and environmental conditions?
3) What observation methods, measurement tools, and technology assisted assessment approaches have been used in current studies, and what are their main applicability and limitations?
4) What spatial barriers, sensory triggers, and design related issues do PMIOD children face in real home and everyday environments?

2. Methods

This study was conducted as a scoping review. The review followed the methodological framework proposed by Arksey and O'Malley (2005), and incorporated the methodological refinements suggested by Levac et al. (2010) and the JBI guidance for scoping reviews (2024). The review was summarized, written, and reported according to the PRISMA-ScR reporting guidelines for scoping reviews (Tricco et al., 2018). Based on the research questions and the interdisciplinary scope of this review, the literature search was conducted in May 2026 across four databases: Scopus, Web of Science, PubMed, and APA PsycINFO/APA PsycArticles through the EBSCOhost platform. These databases were selected to cover engineering and design, rehabilitation and child health, and psychology and behavioral sciences (Bramer et al., 2017). The review period began in January 2015, the calendar year in which the United Nations adopted the 2030 Agenda for Sustainable Development (United Nations, 2015). Within this time frame, the review maps how research on PMIOD children's perceptual behaviors, emotional responses, environmental participation, and related assessment methods in home and everyday environments developed up to May 2026. The search terms and eligibility criteria were mainly developed based on the Population–Concept–Context framework, namely Population, Concept, and Context (Peters et al., 2021, 2024) (Table 1). In this study, Concept was not treated as an intervention outcome variable. Instead, Concept referred to perceptual behaviors, interactive behaviors, exploratory behaviors, and emotional responses related to spatial participation. Context referred to home and everyday living environments.

Table 1
Keyword composition for literature search using the PCC framework.

Element	composition	keyword
Population	Preschool children with physical mobility impairments	"preschool children", "early childhood", "young children", "children" AND "mobility impairment*", "physical disab*", "motor disab*", "cerebral palsy"
Concept	Perception, behavior, and emotional responses in daily activities	"perceptual behavior", "spatial interaction", "exploration behavior", "emotional response", "affective behavior"
Context	Home and daily living environments	"home environment", "domestic setting", "family environment", "everyday activities", "daily living"

The literature search used Boolean logic to combine search terms with 'AND' and 'OR' operators. Search fields were limited to article titles, abstracts, and keywords. Because the review involved multiple factors, the search strategy was organized through segmented retrieval and broader term expansion. Three rounds of searches were conducted separately in each database. The first round used core keyword combinations targeting the main terms related to Population and Concept. The second round expanded the coverage of disability related terms on the basis of the first round, including specific diagnostic terms such as cerebral palsy, spina bifida, limb deficiency, and neuromuscular disorder. This step was used to avoid missing relevant studies that used specific diagnostic labels rather than broader terms such as physical disability. Detailed information is provided in Table 2. After the three search rounds, records were restricted to English language articles and reviews, and database specific subject area restrictions were applied where available (Fig. 1, Table 3).

To reduce literature noise from subject areas clearly unrelated to the review topic, such as chemistry, earth sciences, and agricultural sciences, subject area restrictions were applied in Scopus and Web of Science. The specific subject area restrictions are shown in Table 3. PubMed and APA PsycINFO did not provide subject area filters equivalent to

Table 2
Search strategy summary across databases.

R	Focus Area	Search Objective	Main Search Terms
1	Behavior and Disability	Identify core studies on behavioral patterns of preschool children with mobility impairments	("preschool children" OR "early childhood" OR "young children") AND ("emotion regulation" OR "affective behavior" OR "emotional response") AND ("environment" OR "spatial interaction" OR "home environment" OR "physical setting")
2	Emotional Response and Disability Traits	Retrieve emotional/ affective studies involving preschool children with various mobility impairments	("preschool children" OR "early childhood" OR "young childhood") AND ("emotional response" OR "affective behavior" OR "emotional development" OR "emotion regulation") AND ("mobility impairment*" OR "motor disabilit*" OR "physical disabilit*" OR "cerebral palsy" OR "limb deficienc*" OR "congenital limb deformit*" OR "neuromuscular disorder*" OR "spinal cord injur*" OR "amputation")
3	Broader Contextual Studies	Broaden the scope to identify contextual evidence on environment, spatial interaction, and emotional responses in preschool children.	("preschool children" OR "early childhood" OR "young children") AND ("emotion regulation" OR "affective behavior" OR "emotional response") AND ("environment" OR "spatial interaction" OR "home environment" OR "physical setting")

Note: The same search logic was applied across Scopus, Web of Science Core Collection, PubMed, and APA PsycINFO/APA PsycArticles (via EBSCOhost), covering four interdisciplinary domains. In Scopus, searches were conducted in TITLE ABS KEY. In Web of Science Core Collection, searches were conducted using Topic. In PubMed, searches were conducted in Title/Abstract. In APA PsycINFO and APA PsycArticles via EBSCOhost, equivalent searches were conducted in Title, Abstract, and Subject Terms fields. The three search rounds were conducted separately, and all retrieved records were imported into Zotero for deduplication.

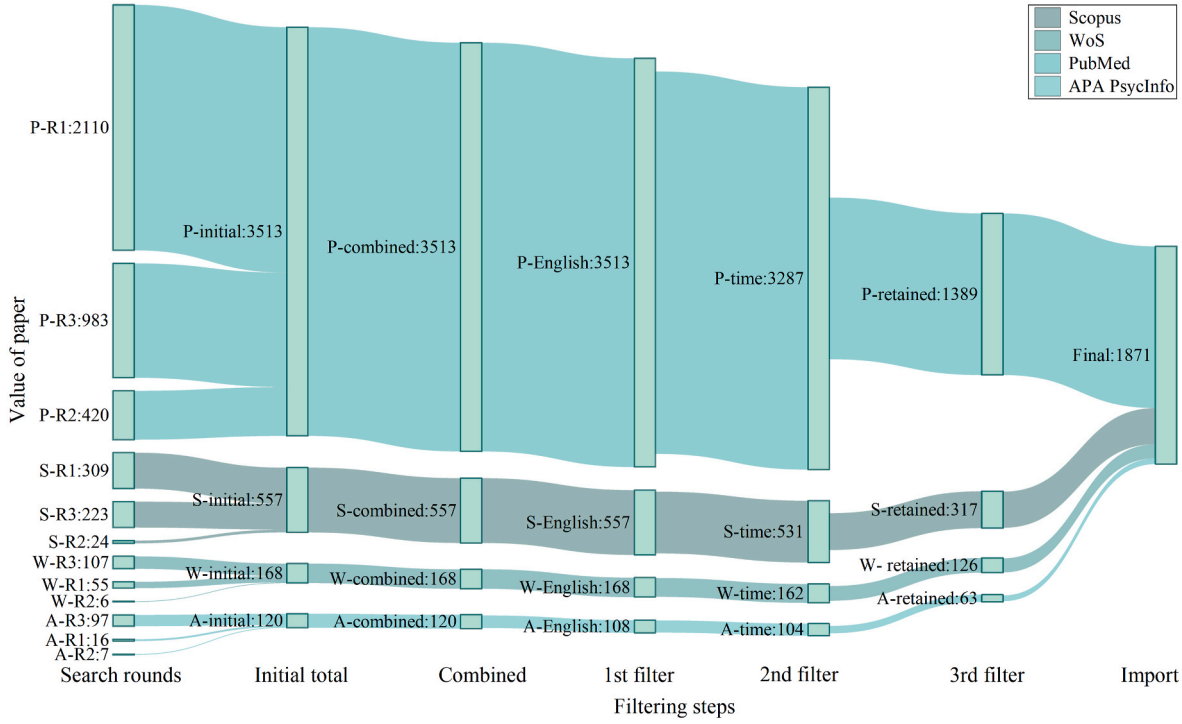

Fig. 1. Database specific search rounds and filtering process before Zotero import.

Table 3
Overview of search rounds, filtering steps, and database-specific restrictions.

Database	Subject Area
Scopus	Medicine, Psychology, Social Sciences, Neuroscience, Health Professions, Nursing, Arts and Humanities, Environmental Science, Engineering
Web of Science	Psychology Developmental, Psychiatry, Education Educational Research, Psychology, Psychology Educational, Psychology Multidisciplinary, Psychology Clinical, Family Studies, Behavioral Sciences, Public Environmental Occupational Health, Pediatrics, Psychology Experimental, Psychology Social, Neurosciences, Rehabilitation, Education Special, Environmental Sciences, Nursing, Social Sciences Interdisciplinary, Sociology, Social Work
PubMed	Not applicable. PubMed does not provide subject area filters comparable to Scopus or Web of Science. Eligibility was determined during title, abstract, and full text screening.
APA PsycArticles	Psychology and behavioral sciences related records were retained. Non journal records, including dissertations and book chapters, were excluded according to the eligibility criteria. No additional subject area filter comparable to Scopus or Web of Science was applied.

Note: PubMed does not provide subject-area filters comparable to Scopus and Web of Science. Article-type and age filters were tested but not retained because they substantially reduced retrieval and did not align precisely with the predefined age range and inclusion logic. Eligibility was therefore determined during title/abstract and full-text screening.

those in Scopus and Web of Science. Therefore, records from these databases were assessed according to the inclusion and exclusion criteria during title and abstract screening and full text eligibility assessment.

All search results from the four databases were imported into Zotero for reference management (n = 1871). After automatic deduplication in Zotero, the researchers manually checked titles, authors, publication years, and DOIs. This process generated an initial non duplicate reference library (n = 1589). After additional prescreening checks, title and abstract screening were conducted according to four aspects: the age range of the study population, disability characteristics, research content, and research method.

First, in terms of age range, the included studies focused mainly on preschool children aged 3–6 years. For studies with sample age ranges that crossed the target age range of this review, such as studies including children aged 2–7 years, the studies were included only when one of the following conditions was met: the median age of the sample fell within the 3–6 year age range, or the study separately reported results for the 3–6 year subgroup. Second, in terms of disability characteristics, the included studies mainly focused on children with mobility impairments or physical movement limitations. These children included, but were not limited to, children with cerebral palsy, children with motor impairments, children with substantial difficulties in postural control or grasping function, children with limb absence, and children with congenital limb deformities. Third, in terms of research content, eligible studies were required to involve at least one perceptual, behavioral, or emotional variable and to be directly related to the core topic of this review. Finally, in terms of research method, empirical studies and review studies using any research design, including quantitative, qualitative, and mixed methods designs, were eligible for inclusion. In accordance with the JBI guidance for scoping reviews (Peters et al., 2024), this review did not conduct methodological quality appraisal. Only formally published original studies and reviews with accessible full texts were included.

On this basis, the records entering the screening process were further reviewed by title and abstract, and the screening decisions were made with reference to full text availability and relevance to the study topic. The exclusion criteria mainly included the following categories: 1) the study population was not children; 2) the study population belonged to a broad group of children with disabilities, but the disability characteristics were not consistent with the physical disabilities, mobility impairments, or related motor function limitations addressed in this review; 3) the research topic differed substantially from the aim of this review and could not provide useful evidence for the analysis of perceptual behavior, emotional expression, or related environmental factors; 4) the study information was incomplete or the full text was unavailable. After screening, 176 studies were finally retained for subsequent analysis. The detailed screening process is shown in the PRISMA 2020 flow diagram (Fig. 2).

The final included studies entered the data charting stage. Data

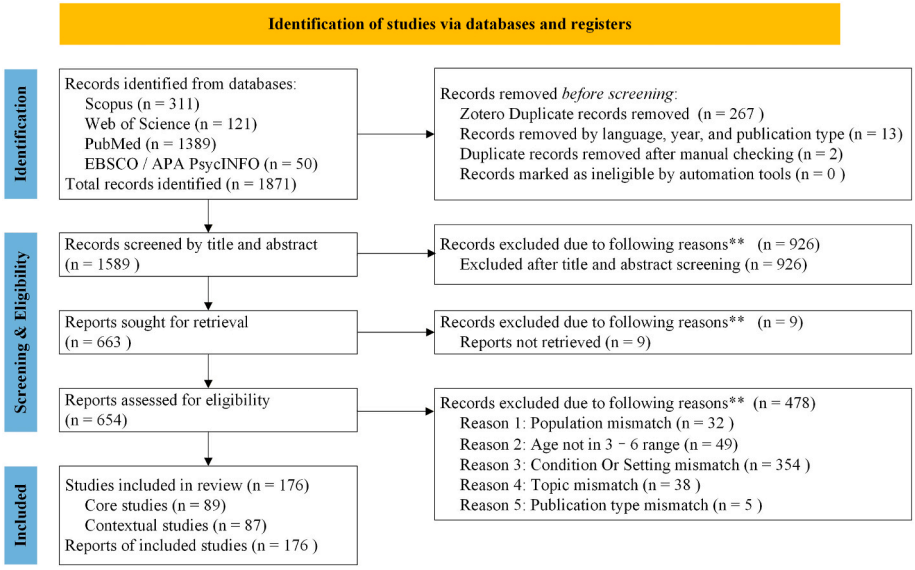

Fig. 2. PRISMA 2020 Flow Diagram showing the selection process of studies.

charting was independently conducted by two researchers, and disagreements were resolved through discussion. Following Arksey and O'Malley (2005) and Peters et al. (2024), a structured data charting form was developed to extract four categories of information (Table 4): A) Population and Context; B) Behavioral Constructs and Outcomes; C) Assessment and Analytic Tools; and D) Research Methodology. No protocol was prospectively registered for this scoping review. During the revision stage, the amended search strategy, database records, eligibility criteria, and data charting framework were archived in an OSF revision stage transparency record. This record should not be interpreted as prospective preregistration.

After export from Zotero, the extracted keywords and terms were cleaned and standardized through three steps: 1) descriptive metadata terms unrelated to the research questions, such as 'male', 'female', 'humans', 'study', and 'article', were removed; 2) synonyms and inconsistent expressions were merged; 3) medical terms that were too broad or not clearly aligned with the constructs of this review were removed. The standardized tag classification was then summarized in Table 5.

The standardized tags were organized according to the four categories of the data charting framework. Population and Context tags described participant characteristics, disability types, and the physical, social, institutional, or cultural contexts addressed in the included studies. Behavioral Constructs and Outcomes covered perceptual, affective, and regulatory responses, interactive and relational processes, exploratory and mobility behaviors, and broader cross-cutting outcomes. Within B1, the tags represented sensory and perceptual processing, attention and cognitive control, affective and emotional reactions, emotion regulation and dysregulation, self-regulation, and physiological regulation. These constructs were grouped for descriptive data charting while retaining their distinct conceptual meanings. Interactive and relational tags described parent–child, caregiver–child, peer, and parent–professional interactions, together with parenting practices, communication, joint attention, and social participation. Exploratory and mobility tags described environmental exploration, play, physical activity, and self-initiated or assisted mobility. Assessment and Analytic Tools included questionnaires and report-based instruments, behavioral checklists and adjustment scales, parenting and family measures, functional and developmental assessments, and scoring, coding, and analytic tools. Within this category, functional and developmental assessments described child-level abilities relevant to participation and interaction with the environment. Research Methodology tags described study designs and frameworks, intervention modalities, data collection methods, and technological platforms and devices. The categories were used as operational data-charting domains and were not mutually exclusive; a standardized term could be assigned to more than one category when it represented different aspects of a study.

3. Results

This review conducted a descriptive summary and thematic synthesis of the 176 included studies, with a focus on the distribution of existing evidence related to perceptual behaviors, emotional responses, spatial experiences, and related measurement methods in PMIOD children. Among the included studies, 89 studies provided direct PMIOD evidence, and 87 studies provided contextual evidence. Within the contextual evidence, 76 studies provided PMIOD related contextual evidence, 7 studies provided broader disability background evidence, and 4 studies provided design or environmental background evidence. This section first presents the keyword structure and coding framework of the included studies. It then summarizes the evidence around behavioral and emotional patterns (RQ1–RQ2), research tools and measurement methods (RQ3), and environmental barriers and design related evidence (RQ4). Table 6 provides a summary of evidence for each research question, and the key patterns are briefly described.

RQ1: perceptual behavior, mobility exploration, and participation; RQ2: emotional responses and related conditions; RQ3: observation methods, measurement tools, and technology assisted assessment; RQ4: environmental barriers, sensory triggers, and design related evidence. Domains were not mutually exclusive, and one study could contribute to more than one research question. Core studies provided direct PMIOD evidence, whereas contextual studies provided supplementary evidence from proxy reports, family and service perspectives, broader disability research, measurement studies, or design and environmental background.

3.1. Overview of included studies and keyword structure

The 176 included studies were published between 2015 and 2026. In relation to behavioral keywords, the standardized terms were organized into three main dimensions: perceptual, affective, and regulatory responses; interactive and relational processes; and exploratory and mobility behaviors. Broader terms spanning several dimensions were

Table 4
Data charting framework for keyword coding and categorization.

Category	Detail	Explanation
A: Population and Context	A1: Sample Characteristics	Participant groups, age categories, and roles represented in the study, such as children, parents, caregivers, teachers, and therapists.
	A2: Disability Types	Specific disabilities, impairments, mobility limitations, or related health conditions addressed in the study population.
	A3: Environmental Setting	Physical, social, institutional, or cultural contexts addressed in the study.
B: Behavioral Constructs and Outcomes	B1: Perceptual, Affective, and Regulatory Responses	Child-level responses involving sensory and perceptual processing, attention and cognitive control, affective and emotional reactions, emotion regulation and dysregulation, self-regulation, and physiological regulation.
	B2: Interactive and Relational Processes	Parent–child, caregiver–child, peer, and parent–professional interactions, including parenting practices, communication, joint attention, social engagement, and social participation.
	B3: Exploratory and Mobility Behaviors	Behaviors related to environmental exploration, play, physical activity, self-initiated or powered mobility, stair use, and wheelchair skills.
	B4: Cross-Cutting Outcomes	Broad outcomes spanning adaptive and problem behaviors, functional abilities, participation, quality of life, socioemotional development, school readiness, and mental health.
C: Assessment and Analytic Tools	C1: Questionnaires and Report-Based Instruments	Questionnaires, surveys, satisfaction measures, and parent- or caregiver-reported measures.
	C2: Behavioral Checklists and Adjustment Scales	Structured instruments used to assess behavioral characteristics, adjustment, and developmental behavior.
	C3: Parenting and Family Measures	Measures of parenting, parental stress, family adjustment, family-centered care, caregiver sensitivity, and the family emotional climate.
	C4: Functional and Developmental Assessments	Classification systems and standardized assessments of motor and physical function, cognitive and developmental abilities, self-regulation, and daily functional performance.
	C5: Scoring, Coding, and Analytic Tools	Tools and procedures used to score, code, or analyze observational, behavioral, physiological, qualitative, and quantitative data.
D: Research Methodology	D1: Study Designs and Frameworks	Research designs and methodological frameworks represented in the included studies, including cross-sectional, longitudinal, controlled, experimental, qualitative, mixed-methods, case, validation, and review designs, as well as conceptual frameworks.
	D2: Intervention Modalities	Intervention, training, rehabilitation, or service-delivery approaches examined in the included studies.
	D3: Data Collection Methods	Procedures used to collect or document study data, including observation, video-based coding, interviews, focus groups, surveys, field notes, and outcome or physiological assessments.
	D4: Technological Platforms and Devices	Digital systems, sensors, assistive devices, and other technologies used for data collection, intervention, communication, or mobility support.

Table 5
Tag cleaning rules for keyword standardization.

Cleaning principle	Original tag examples	Standardized tag examples
Merge age and participant descriptors	child, children, preschool child, toddlers, parents, caregivers	children, preschool_children, toddlers, parents, caregivers
Standardize disability terms	handicapped child, disabled child, physical disabilities, CP, motor dysfunction	physical_disability, cerebral_palsy, motor_impairment
Standardize environmental settings	home environment, family environment, daycare, school, institutional care	home_environment, daycare_environment, school_context, institutional_care
Standardize perceptual, affective, and regulatory constructs	emotion, emotional regulation, affect, attention, inhibitory control, sensory processing, physiological regulation	emotion_regulation, affective_response, attention, inhibitory_control, sensory_processing, physiological_regulation
Standardize interaction and participation terms	parent child relation, peer group, communication, social participation	parent_child_interaction, peer_play, communication, social_participation
Standardize exploratory and motor activity terms	locomotion, physical activity, powered mobility, environmental exploration	motor_exploration, physical_activity, powered_mobility, environmental_engagement
Standardize assessment tools	questionnaire, survey, checklist, CBCL, GMFCS, PEDI-CAT	questionnaire, behavior_checklist, motor_function_scale, PEDI_CAT
Standardize research methods	cross-sectional study, RCT, interview, focus group, observation	cross_sectional, randomized_controlled_trial, interview, focus_group, observation
Standardize technology terms	wearable sensor, eye-gaze technology, EEG, augmented reality	wearable_sensor, eye_gaze_assistive_technology, EEG, augmented_reality

classified as cross-cutting outcomes (B4). Some standardized terms could occur in more than one analytical category. For example, parenting appeared in B2 and D2 when it described relational processes and intervention modalities, respectively. The distribution of standardized keywords across categories is summarized in Table 7.

In VOSviewer, this study used standardized keywords to construct a co-occurrence network. As shown in Fig. 3, the co-occurrence analysis included only keywords that appeared in at least 5 studies. The final network contained 74 nodes, 1145 links, and 5 clusters, with a total link strength of 2511. The keyword network showed that PMIOD related studies mainly revolved around themes such as children with disabilities, cerebral palsy, physical activity, participation, caregivers, parents, quality of life, communication, rehabilitation, and family support.

From the perspective of cluster structure, clear intersections were observed across different clusters. The red cluster was mainly associated with keywords such as children with disabilities, physical activity, play, wheelchair use, motor function, and participation. This cluster reflected research related to mobility ability, physical activity, and participation

Table 6
Evidence synthesis summary aligned with research questions.

Q	N	Main samples and settings	Main methods and tools	Key patterns
1	61/28	PMIOD children and related proxy or service perspectives; home, school, rehabilitation, play, and community settings	Observation, video coding, parent report, participation measures, mobility assessment	Reduced exploration opportunities; path movement difficulties; obstacle avoidance problems; limited play participation; lower action autonomy
2	45/56	PMIOD children, caregivers, and family support contexts; home, clinical, school, and service settings	Proxy report, interview, emotional and behavioral scales, HRQoL tools, qualitative synthesis	Anxiety, frustration, insecurity, withdrawal, pain or fear related responses, positive emotional responses; links with physical limitations, caregiver support, accessibility, autonomy, and participation quality
3	24/21	PMIOD children, caregivers, therapists, educators, and measurement related studies	Questionnaires, interviews, behavioral coding, functional scales, participation measures, audio recording, EEG, wearable sensors	Frequent use of proxy reports and questionnaires; situated behavioral evidence from observation and video coding; supplementary use of technology assisted methods
4	25/11	PMIOD and broader disability related contexts; home, daycare, school, community, rehabilitation, and design settings	Environmental participation measures, qualitative interviews, intervention observation, sensory environment assessment, design related evidence	Accessibility, path continuity, assistive device fit, and mobility constraints were more frequently addressed, while direct evidence on materials, color, lighting, tactile stimulation, spatial scale, and real home spatial design remained limited

Note: Domains were not mutually exclusive. One study could contribute to more than one research question. N: Core/Contextual.

behavior. The green cluster mainly revolved around cerebral palsy, physical disability, quality of life, functional ability, mobility limitation, and caregivers. This cluster reflected the relationships among PMIOD related diagnoses, functional status, and quality of life. The blue cluster involved more terms related to anxiety, depression, psychological adaptation, emotion, parenting stress, and parent child interaction. This cluster reflected research on emotional and psychosocial outcomes. The yellow cluster mainly included parents, family centered services, professionals, service delivery, and satisfaction. This cluster indicated that family support and professional service relationships occupied an important position in the relevant studies. The purple cluster was smaller and mainly connected communication, language, professional relationships, and some measurement or support related terms. This cluster reflected evidence related to communication support and service interaction.

Overall, the core evidence in PMIOD child research was concentrated on the intersecting relationships among mobility function, physical activity, participation, quality of life, family caregiving, and emotional and psychosocial outcomes. At the same time, keywords directly related to real home spaces, spatial design, sensory environments, and the fit between assistive devices and spaces were less prominent. This pattern suggests that environment and design related evidence remains

Table 7
Standardized keyword classification and frequency statistics.

Detail	Standardized Keywords	N
A1	children, preschool_children, infants, toddlers, young_children, children_and_youth, parents, mothers, caregivers, teachers, therapists	89/86
A2	physical_disability, cerebral_palsy, developmental_disability, developmental_delay, motor_impairment, mobility_limitation, wheelchair_use, severe_physical_disability, acquired_brain_injury, spinal_muscular_atrophy, neuromotor_delay, musculoskeletal_disorders, VACTERL_association	89/84
A3	home_environment, family_environment, daycare_environment, preschool_environment, school_context, rehabilitation_setting, clinical_setting, institutional_care, inclusive_preschool, physical_environment, acoustic_environment, social_context, cultural_context	80/80
B1	sensory_processing, auditory_perception, visual_perception, attention, cognitive_response, inhibitory_control, effortful_control, affective_response, emotional_response, emotion_regulation, emotion_dysregulation, self_regulation, physiological_regulation	53/51
B2	parent_child_interaction, parenting, parenting_practices, caregiver_child_interaction, parent_therapist_interaction, peer_play, communication, joint_attention, social_interaction, social_engagement, social_participation, dyadic_interaction	57/59
B3	motor_exploration, environmental_engagement, environmental_exploration, object_play, pretend_play, play_behavior, physical_activity, self_initiated_mobility, powered_mobility, stair_climbing, wheelchair_skills	74/56
B4	behavior, problem_behavior, behavioral_problems, disruptive_behavior, adaptive_behavior, developmental_behavior, functional_abilities, developmental_outcomes, participation, quality_of_life, health_related_quality_of_life, socioemotional_development, school_readiness, mental_health	34/47
C1	questionnaire, survey, online_survey, parent_report, caregiver_report, satisfaction_measure, parent_perspective	31/33
C2	behavior_checklist, checklist, adjustment_scale, developmental_behaviour_checklist	9/4
C3	parenting_scale, parenting_stress_index, parental_stress, family_adjustment, family_centered_care, caregiver_sensitivity, maternal_sensitivity, family_emotional_climate, parental_appraisal	13/26
C4	motor_function_scale, cognitive_scale, cognitive_assessment, developmental_scale, self_regulation_index, physical_function_assessment, GMFCS, GMFM, PEDI_CAT	44/32
C5	scoring_system, rating_scale, observational_coding, behavioral_coding, physiological_scoring, qualitative_coding, thematic_analysis, framework_analysis, structural_equation_modeling, path_model, multilevel_modeling	17/9
D1	cross_sectional, longitudinal_study, follow_up, controlled_study, randomized_controlled_trial, quasi_experimental_study, qualitative_study, mixed_methods, case_study, validation_study, systematic_review, scoping_review, conceptual_framework	55/48
D2	parent_training, parenting_intervention, early_intervention, collaborative_intervention, powered_mobility_intervention, modified_ride_on_car, treadmill_intervention, music_intervention, piano_therapy, snoezelen_intervention, home_exercise_program, telehealth, online_intervention	32/13
D3	observation, video_coding, interview, focus_group, survey, outcome_assessment, physiological_assessment, qualitative_interview, parent_interview, field_notes	59/46
D4	online_system, e_health_platform, teleconsultation, wearable_sensor, inertial_sensor, eye_gaze_assistive_technology, assistive_technology, powered_mobility_device, EEG, augmented_reality, interactive_technology	20/7

Note: A1: Sample Characteristics; A2: Disability Types; A3: Environmental Setting. B1: Perceptual, Affective, and Regulatory Responses; B2: Interactive and Relational Processes; B3: Exploratory and Mobility Behaviors; B4: Cross-Cutting Outcomes. C1: Questionnaires and Report-Based Instruments; C2: Behavioral Checklists and Adjustment Scales; C3: Parenting and Family Measures; C4: Functional and Developmental Assessments; C5: Scoring, Coding, and Analytic Tools. D1: Study Designs and Frameworks; D2: Intervention Modalities; D3: Data Collection Methods; D4: Technological Platforms and Devices. Counts are reported as Core/Contextual. Core studies provide direct PMIOD evidence, whereas Contextual studies provide PMIOD-related contextual evidence, broader disability evidence, measurement background, design and environmental background. Categories were not mutually exclusive.

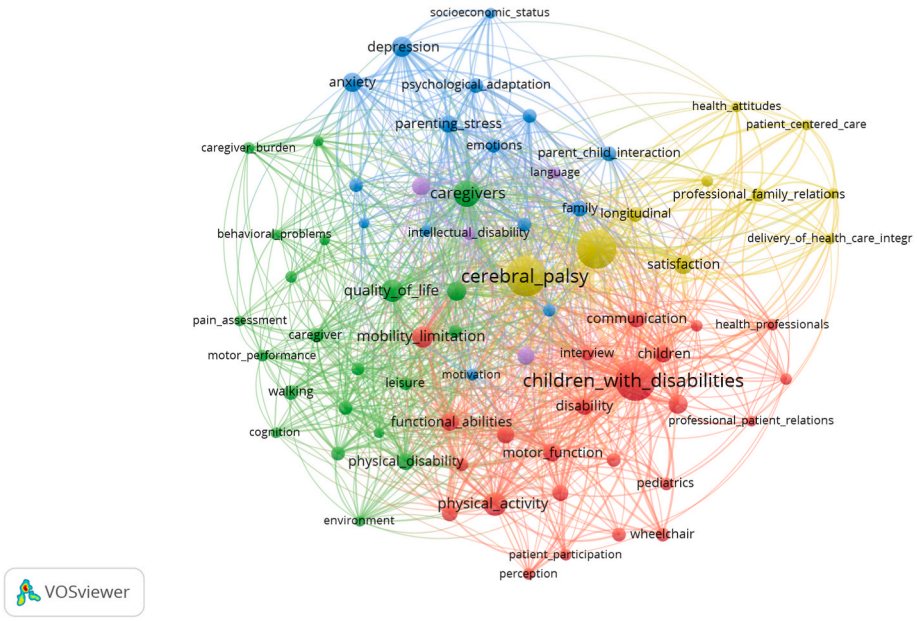

Fig. 3. Co-occurrence network of standardized keywords in the reviewed studies (n ≥ 5)
Note: The network was generated from standardized data charting keywords extracted from the 176 included studies, including both core and contextual studies. Keywords were coded and standardized according to the A1–D4 data charting framework and the keyword cleaning rules described in Tables 4–7. Synonymous or variant terms were normalized using a thesaurus; for example, "emotion regulation" and "emotional regulation" were merged into emotion_regulation, and metadata terms unrelated to the review focus were excluded. The minimum occurrence threshold was set to five, resulting in 74 keywords, 1145 links, and five clusters. Node size represents keyword frequency, line thickness represents co-occurrence strength, and cluster colors indicate groups of frequently co-occurring keywords generated by VOSviewer. This map represents standardized data charting keywords rather than original author keywords. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

relatively dispersed and marginal in the current literature.

Based on the keyword structure and the co-occurrence network, this review summarizes the included evidence from the following four aspects: 1) behavioral and emotional patterns of PMIOD children in environmental contexts; 2) assessment tools, observation protocols, and measurement methods used in existing studies; 3) spatial barriers, sensory triggers, and design related evidence in real home and everyday environments; and 4) secondary developmental risks and methodological challenges in early intervention.

3.2. Behavioral and emotional patterns in environmental contexts

The included studies showed that the behavioral and emotional patterns of PMIOD children in everyday environments were mainly associated with physical motor function, assistive device use, family caregiving relationships, activity opportunities, and environmental support (Albrecht & Khetani, 2017; Barchus et al., 2023; Bloemen et al., 2015; Hansen et al., 2025). The current evidence can be synthesized into four main aspects: environmental exploration, mobility, and navigation; play participation, dependence, and autonomy; emotional expression, anxiety, comfort, and security; and secondary developmental risks and intervention challenges.

3.2.1. Environmental exploration, mobility, and navigation

In terms of spatial exploration and mobility, PMIOD children usually face more restrictions than their peers. These restrictions are jointly shaped by children's functional levels, access to assistive devices, the accessibility of the physical environment, and forms of caregiver support. The included studies mainly addressed this issue from three aspects: restricted exploration opportunities, support from assistive mobility devices, and navigation and environmental accessibility.

First, because of physical disabilities or mobility limitations, children who cannot move independently are restricted in both the quantity and quality of their contact with the environment. These restrictions may further affect children's environmental exploration, interaction opportunities, and learning experiences (Barchus et al., 2023; Gijbels et al., 2026; Valentín-Gudiol et al., 2017), and may also alter their spatial behavior patterns (Logan et al., 2017; Ross et al., 2018; Wilson et al., 2016). Valentín-Gudiol et al. (2017) reported that delayed motor development can limit children's exploration of the environment and may hinder their cognitive and socioemotional development. As a result, PMIOD children often have fewer opportunities for autonomous mobility and communication (Barchus et al., 2023; Gijbels et al., 2026), and they may also have fewer opportunities to acquire exploratory experience in space (Gijbels et al., 2026; Valentín-Gudiol et al., 2017). When children remain for long periods within small or fixed activity areas, their opportunities to understand spatial entry, exit, directional change, and environmental stimuli may also decrease (Lin & Chang, 2015; Valentín-Gudiol et al., 2017). This may be reflected in reduced active approach behaviors toward the environment, increased dependence on adult support, and relatively delayed spatial cognitive development (Logan et al., 2017). As children grow older, activity opportunities for children with CP at GMFCS levels III–V in home or community environments may become further restricted (Orlando et al., 2025). Studies on physical activity also show that mobility status, physical function, device availability, and local facility conditions can affect the activity participation levels of children with physical disabilities (Bloemen et al., 2015; Wilson et al., 2016). Long term trajectory research further suggests that ability for mobility follows different developmental pathways according to age and functional level. Therefore, the mobility ability of PMIOD children should not be understood as a fixed or unchanged state (Smits et al., 2019). Overall, restricted spatial exploration in PMIOD children is reflected not only in reduced movement distance but also in fewer opportunities for active approach, active choice, and active participation.

Second, assistive mobility devices and related technologies have potential to support the environmental participation of PMIOD children and may expand their opportunities for environmental exploration

(Carmo Rodrigues Almeida et al., 2021). Studies on modified ride on cars, Explorer Mini, powered mobility devices, and wheelchair training suggest that when PMIOD children obtain operable mobility tools, their autonomous mobility, play participation, and peer interaction may change (Sloane et al., 2024). ROC training has also been associated with changes in children's mastery motivation and parental stress (Barchus et al., 2023; Gijbels et al., 2026; Huang et al., 2022; Logan et al., 2017; Plummer et al., 2021; Ross et al., 2018). In an observation of toddlers with mobility limitations using Explorer Mini for the first time, Plummer et al. (2021) found that most children were able to move the device and attempted to explore the environment. Beyond mobility assistive devices, some robotic or interactive technologies have also been used in rehabilitation and special education settings. However, this evidence mainly reflects the feasibility of technology assisted interaction rather than directly verifying spatial navigation ability (Van Den Heuvel et al., 2017). These technologies may enhance PMIOD children's willingness to interact with physical environments, support autonomous action and exploratory behavior, and promote environmental participation and social exploration (Barchus et al., 2023; Logan et al., 2017). In recreational areas and classrooms, powered mobility devices have also been reported to improve children's environmental participation and social exploration and to help them overcome some exploration difficulties (Ross et al., 2018). Although early intervention may improve autonomous mobility, sense of control, and exploration opportunities in PMIOD children (Barchus et al., 2023), children's opportunities for exploration and mobility continue to depend substantially on adult supervision, device fit, and environmental conditions (Logan et al., 2017).

In addition, assistive mobility devices can expand the range of exploration, but these devices do not automatically solve navigation, obstacle avoidance, or environmental access problems. Even when PMIOD children have access to assistive mobility devices, they may still face practical difficulties in navigating community environments, managing obstacles, and receiving relevant skills training (Gijbels et al., 2026; Ouellet et al., 2022, 2024). In addition to spatial exploration itself, some studies have examined children's turning, path judgment, and obstacle handling abilities. Ouellet et al. (2022) reported that many child wheelchair users with CP had not yet mastered basic manual wheelchair skills. Existing powered mobility studies have also been conducted mainly in laboratories, playgroups, or training contexts, and direct measurement of path judgment, obstacle avoidance, and spatial navigation in real home spaces remains limited (Gijbels et al., 2026). Therefore, when PMIOD children use modified mobility devices, additional steering assistance, obstacle avoidance support, and caregiver supervision are often still needed to ensure the safety and effectiveness of mobility (Aldrich, Kenyon, et al., 2025; Ross et al., 2018; Sloane et al., 2024). At the same time, caregivers' understanding of children's mobility ability and device use can also affect how children obtain assistive mobility experiences and learn to use mobility devices (Aldrich, Vanderest, et al., 2025).

It should also be noted that although assistive mobility devices can expand exploration opportunities to some extent, their actual effects are influenced by environmental accessibility (Alemdaroğlu-Gürbüz & Karakuş, 2019; Barchus et al., 2023; Gijbels et al., 2026; Logan et al., 2017; Ross et al., 2018). Powered mobility and other assistive devices can increase the active exploration space of children with mobility impairments, but the devices themselves cannot remove all environmental barriers. Device fit, training quality, and environmental adaptation are key factors affecting children's independent mobility (Kennedy et al., 2020; Ouellet et al., 2024). Passage width, path continuity, turning conditions, and safety support can all influence assistive device use. Young children with physical disabilities in daycare environments may also require additional physical support, adult assistance, and environmental adaptation in order to participate more fully in activities (Bossi et al., 2021). In addition, findings from studies on typically developing preschool children regarding space and furnishings and children's physical fitness may provide contextual evidence for understanding how physical environments affect children's activity participation (Liao et al., 2025). For PMIOD children, inaccessible environments may therefore become additional barriers to participation (Barchus et al., 2023).

Furthermore, children's exploratory behavior should not be understood as an isolated motor outcome. Children's functional limitations do not directly determine participation. Instead, functional limitations may affect children's home participation indirectly through caregivers' perceptions of environmental support (Albrecht & Khetani, 2017). Some studies suggest that daycare, family, and preschool environmental support can influence whether children gain opportunities for exploration (Bossi et al., 2021; Kang et al., 2017). Participation opportunities and participation quality should also be distinguished. The mobility ability of children with physical disabilities is associated to some extent with active physical leisure participation, but children's sense of agency, interaction quality, and autonomy during activities are also important (Barchus et al., 2023). Therefore, the spatial exploration of PMIOD children cannot be judged only by whether children move, whether children participate, or how many activities children participate in. Because disability types, mobility abilities, and support needs differ substantially, some children may show levels of participation diversity similar to those of other children, but they may still experience limitations in social competence, interaction quality, and autonomous exploration (Phillips & Hogan, 2015).

3.2.2. Play, participation, dependence, and autonomy

The play related behavioral patterns of PMIOD children were mainly reflected in play opportunities, peer interaction, forms of activity participation, and differences in autonomy. In play contexts, PMIOD children may have fewer opportunities for peer interaction, a higher proportion of solitary play, and insufficient diversity in play behaviors (Logan et al., 2015; Ross et al., 2018). Because PMIOD children may need to expend more energy and receive more assistance during activities, their activity speed is also lower than that of typically developing children (Logan et al., 2015, 2017). In some studies and specific play contexts, modified ride on cars were observed to reduce solitary play and increase parallel play or peer interaction (Logan et al., 2017; Ross et al., 2018). In addition, PMIOD children may participate in a similar number of activities as their peers, but their social competence may still be lower (Phillips & Hogan, 2015). This suggests that the number of activities does not necessarily represent the quality of participation. Whether PMIOD children can develop stable peer interaction, active choice, and social participation in activities still needs to be understood in relation to specific play contexts and support conditions. From educators' perspectives, PMIOD children require additional physical support, adult assistance, and environmental adaptation to participate in play and activities in daycare environments (Bossi et al., 2021; Nijs et al., 2016).

From the perspective of everyday activities and environmental participation, the participation of PMIOD children is influenced by multiple factors, including mobility ability, environmental support, transportation conditions, adult assistance, and accessible environments (Albrecht & Khetani, 2017; Kang et al., 2017; Ouellet et al., 2024; Ssemata et al., 2025; Van Keer et al., 2019). Lindsay (2016) reported that the participation of children with cerebral palsy in school, community, and recreational activities is affected by transportation, accessibility, safety, weather, and physical environmental conditions. Studies on modified ROC use and wheelchair use also indicate that being able to go where children want to go and being able to participate in everyday life are important components of quality of life (Bray et al., 2017). Beyond children's own disability related limitations, caregivers' perceptions of environmental support can indirectly affect children's participation in home activities (Albrecht & Khetani, 2017). Family centered service models are associated with the participation experiences and family empowerment of children with physical disabilities. The lack of play and activity participation is evident not only in school and rehabilitation environments but also in everyday family activities

(Van Keer et al., 2019). Therefore, even when PMIOD children participate in a similar number of activities, their social and emotional developmental outcomes may still differ from those of their peers (Phillips & Hogan, 2015).

Dependence and autonomy are also important factors for understanding how PMIOD children integrate into social interaction and how their development is affected (Lillo-Navarro et al., 2015; Sloane et al., 2024). PMIOD children often require more adult support and environmental assistance when entering spaces, transitioning between activities, approaching toys, or approaching peers (Steinhart et al., 2018). This dependence is not determined only by children's physical function. It is also related to spatial accessibility, assistive device fit, and adult caregiving arrangements (Aldrich, Vanderest, et al., 2025; Sloane et al., 2024; Steinhart et al., 2018). In intervention contexts, inclusive play opportunities and social groups can increase play opportunities for PMIOD children and reduce participation gaps (Ross et al., 2018). However, some studies also indicate that children's overall play behaviors and participation patterns may not change significantly after intervention. Assistive or technology supported approaches, such as ROC, the ZORA robot, and early powered mobility experiences, may provide PMIOD children with more ways and opportunities for autonomous mobility, thereby reducing assisted dependence and promoting spatial exploration and social autonomy (Barchus et al., 2023; Feldner, 2019; Van Den Heuvel et al., 2017). Interview studies with wheelchair using children and families also show that deciding where to go, how to move, and whether to participate in everyday life are important components of quality of life and autonomy experience (Bray et al., 2017). Caregivers also reported that PMIOD children rarely have opportunities to move independently away from adults, meaning that their entry into and exit from spaces are usually decided by adults (Barchus et al., 2023; Bossi et al., 2021), Zschorn and Shute (2016) also showed that parents frequently mentioned family adaptation, caregiving burden, and continuous involvement in children's everyday activity arrangements when explaining children's physical disability experiences.

In terms of autonomy, powered mobility devices, modified ride on cars, Explorer Mini, and wheelchair skills training more directly support the possibility that children may shift from passive dependence to active mobility and active exploration (Barchus et al., 2023; Gijbels et al., 2026; Ouellet et al., 2022; Plummer et al., 2021; Sloane et al., 2024). Plummer et al. (2021) showed that most toddlers with mobility limitations were able to drive Explorer Mini independently to explore the environment and showed active approach behaviors toward people and objects. When children used modified ride on cars, they could decide where to go, when to start, and when to stop. When controlling the device, children therefore showed stronger positive emotional responses, such as excitement, concentration, and joyful expression (Barchus et al., 2023; Plummer et al., 2021). However, the developmental pathway from dependence to autonomy is influenced by multiple factors (Kao et al., 2020). Powered mobility intervention may enhance the sense of agency of toddlers with motor disabilities and support their shift from being moved by adults to actively choosing and controlling their direction of movement (Gijbels et al., 2026). Ouellet et al. (2022) also reported that after community wheelchair skills training, children with cerebral palsy and spina bifida improved their wheelchair skills, confidence, and participation satisfaction. Kenyon et al. (2017) further showed that home based BWSTT training is feasible and may improve functional mobility in PMIOD children through home based intervention, thereby supporting their participation in home and community environments. Short term intensive neurodevelopmental treatment can improve participation and functional performance in PMIOD children, but the long term maintenance of these effects requires continuous environmental and strategic support (Evans-Rogers et al., 2015). Family centered services therefore emphasize parental participation in decision making, respect for family goals, and support for children's participation in everyday life (Almasri et al., 2018). Taken together, the play and participation issues of PMIOD children should not be understood only as insufficient activity quantity. These issues also require attention to autonomous choice, peer interaction quality, forms of adult support, and changes in agency brought by assistive devices.

3.2.3. *Emotional expression, comfort, anxiety, and security*

PMIOD children may experience more difficulties in emotion regulation, behavior, and socioemotional development, often manifested as anxiety, withdrawal, increased emotional reactivity, and insufficient socioemotional development (Balaji et al., 2026; Hansen et al., 2025). Belmonte-Darraz et al. (2021) reported that children with CP made more errors in emotion knowledge tasks, and that emotion knowledge was positively associated with emotion regulation ability and negatively associated with behavioral problems. This finding suggests that deficits in emotion cognition may be a preceding factor in emotion regulation difficulties and behavioral problems. Studies on children with dyskinetic cerebral palsy also suggest that anxiety, social relationship problems, sleep problems, and other behavioral manifestations may be related to developmental status and quality of life (Saini et al., 2025). Children with spinal muscular atrophy may also face behavioral and emotional challenges, which indicates that the emotional health of children with physical disabilities requires attention (Balaji et al., 2026). However, existing studies are mostly cross sectional and parent reported, and they often focus on negative emotional expression, peer relationships, and exploratory behaviors. Therefore, in addition to physical and mobility impairments, the socioemotional development of PMIOD children should also receive attention (Hansen et al., 2025). At the same time, the development of children's emotion regulation is influenced by family parenting, parent-child relationships, and caregivers' psychological status. Studies on parent child interaction in children with CP show that maternal depression, anxiety, or stress is associated with reduced emotional availability in parent child interaction (Barfoot et al., 2017). Emotional distress in mothers or caregivers may also affect their observation and reporting of children's emotional and behavioral problems (Silberg et al., 2016). Caregiving specific worry, affiliate stigma, and perceived social support among caregivers of PMIOD children are also associated with family caregiving factors such as caregivers' psychological distress (Ma & Mak, 2016).

More specifically, anxiety, distress, and insecurity in PMIOD children are often related to pain, fatigue, mobility difficulties, environmental inaccessibility, and social exclusion, rather than being purely individual psychological problems. For example, children and young people with cerebral palsy often report pain, fatigue, bodily unpredictability, transportation limitations, insufficient accessibility, and safety issues, all of which can affect their everyday participation experiences (Lindsay, 2016). Pain, low self-esteem, and lower functional ability may also be associated with emotional problems in children with cerebral palsy (Belmonte-Darraz et al., 2021). When children cannot freely enter the spaces they want to access, or when they are blocked by the absence of ramps, elevators, or other facilities, they may experience frustration and a sense of exclusion (Bray et al., 2017). Pain and fear should also be assessed separately when researchers examine the emotional experiences of children with CP (Smith et al., 2025). In addition, the home participation of PMIOD children is related not only to children's own abilities but also to caregivers' perceptions of environmental supportiveness (Albrecht & Khetani, 2017). Social exclusion and stigma may further intensify negative emotional experiences among children and caregivers (Lindsay, 2016).

At the same time, children's emotional experiences in the environment are closely related to autonomous mobility, participation quality, and communicative agency. Bray et al. (2017) reported that when wheelchair using children are pushed by adults rather than moving autonomously, the children may feel a lack of autonomy and a sense of exclusion. Restricted participation is not only reflected in participating in fewer activities. It may also be reflected in insufficient interaction quality, peer relationships, or social inclusion, thereby affecting socioemotional experiences (Phillips & Hogan, 2015). In contrast, assistive

mobility devices may provide children with more autonomous mobility and a stronger sense of control. Before using ROC, children had few opportunities to move independently or move away from adults, whereas after using ROC, children gained more freedom and a stronger sense of control (Barchus et al., 2023). Plummer et al. (2021) observed toddlers driving powered mobility devices for the first time and found that children displayed positive emotional responses such as smiles, laughter, and excitement when they could control the device, but showed frustration and crying when the device did not respond. After powered mobility intervention, children also showed a stronger sense of agency and more goal directed mobility (Gijbels et al., 2026). In play environments, modified ride on cars were observed to change children's participation modes and peer interaction (Ross et al., 2018). In gymnasiums and playgrounds, assistive devices also changed the proportions of interaction between children with physical disabilities and peers or teachers (Logan et al., 2017). At the communication level, when children with complex needs used eye gaze technology, their interaction patterns with communication partners changed. Children's active expression increased, while communication partners' dominant questioning decreased (Hsieh et al., 2021).

Comfort and security in space also have important effects on children's emotional experiences. For example, Snoezelen multisensory environments provide children with controllable and comfortable experiences through visual, auditory, tactile, and relaxing stimuli, including fiber optic lights, bubble tubes, music, tactile panels, massage mats, waterbeds, beanbag chairs, and sensory swings. This intervention can reduce problem behaviors in children with cerebral palsy (M. Kim et al., 2025). However, improvement in emotional reactivity was negatively associated with the severity of motor impairment. In that study, children with higher GMFCS levels benefited less. Therefore, the actual effect of this type of sensory environmental support on children with severe mobility impairments remains limited. In addition, PMIOD children's own activity ability and participation level are also important factors that promote comfort (Ouellet et al., 2022). In music therapy, neurophysiological synchrony was observed between children with severe physical disabilities and their parents, suggesting that supportive interactive environments may promote emotional connection (Samadani et al., 2021). Correspondingly, a synthesis of experiences of children and young people with cerebral palsy showed that the social support system formed by families and peers, together with the sense of belonging it brings, is an important factor in relieving emotional stress (Lindsay, 2016).

3.2.4. Secondary developmental risks and intervention challenges

Limited mobility opportunities during the preschool stage may expose PMIOD children to secondary developmental risks (Hsieh et al., 2021; Valentín-Gudiol et al., 2017; Wilson et al., 2016). These challenges are reflected not only in limited intervention effects, but also in device fit, caregiver preferences, family implementation burden, and insufficient training resources (Aldrich, Vanderest, et al., 2025; Carmo Rodrigues Almeida et al., 2021; Lillo-Navarro et al., 2015; Sloane et al., 2024). Children with mobility limitations are less likely to meet daily physical activity guidelines and may have longer sedentary time and a higher risk of being overweight (Wilson et al., 2016). For children with cerebral palsy who have not yet walked independently, studies have also begun to use wearable sensors to objectively distinguish active movement from sedentary time (Orlando et al., 2025). Existing evidence suggests that restricted mobility and limited spatial exploration may be associated with passive participation, reduced self-efficacy, and socio-emotional risks in PMIOD children (Barchus et al., 2023).

At the same time, motor developmental delay itself can restrict children's exploration of the environment and may further hinder cognitive and socioemotional development (Valentín-Gudiol et al., 2017). In boys with Duchenne muscular dystrophy, motor, cognitive, language, behavioral, and socioemotional problems often co-occur and interact with one another (Hoskens et al., 2024). Studies on early intervention and family or professional support suggest that intervention effects depend not only on children's functional status but also on family implementation, the quality of professional interaction, and continuous support (Evans-Rogers et al., 2015; Morera-Balaguer et al., 2023). These risks may be further amplified when external activities and rehabilitation support are interrupted. For example, during COVID-19 lockdowns, the emotions, behavior, and rehabilitation continuity of children with physical disabilities were clearly affected (Cacioppo et al., 2021). Studies of children with SMA also show that some children experience behavioral and emotional difficulties, which create continuous burdens for families (Balaji et al., 2026).

In addition, mobility limitations may delay children's transition from caregiving dependence to autonomy (Kao et al., 2020). Although assistive tools and interventions such as modified ride on cars may help improve PMIOD children's perceptual abilities and social interaction participation, young children still lack highly adapted devices and supportive environments (Logan et al., 2017). Current studies also show that interventions still have limited effects on improving overall gross motor function and helping PMIOD children acquire walking and standing related skills (Valentín-Gudiol et al., 2017). The transfer of responsibility for everyday tasks from parents to children themselves may also be more complex among children with disabilities (Steinhart et al., 2018). Longitudinal caregiving studies further suggest that the convenience of physical caregiving in families of children with CP follows different trajectories according to GMFCS level, and families of children with severe disabilities may require more continuous physical support and caregiving adaptation (Alghamdi et al., 2020). Studies on assistive tools such as ride on cars (ROC) and treadmill interventions indicate that these interventions have potential benefits but also face substantial challenges (Barchus et al., 2023; Ross et al., 2018). In relation to long term developmental outcomes, clinicians can use prediction models to identify children at risk of reduced HRQOL and recommend timely interventions to improve health related quality of life (HRQOL). Some PMIOD children showed a trend of HRQOL improvement within two years after intervention (Church et al., 2025). Although current studies have not directly resolved secondary developmental risks, they highlight the importance of improving mobility and social interaction participation in PMIOD children in order to prevent and reduce secondary problems related to physical mobility limitations.

3.3. Assessment tools, observation protocols, and measurement approaches

The included studies showed that most current research uses proxy reports, questionnaires, interviews, behavioral coding, standardized functional scales, and technology assisted measurement to assess behavioral and emotional responses in PMIOD children. These methods remain relatively dispersed. An integrated measurement system that can simultaneously connect functional ability, behavioral performance, emotional state, and specific spatial environments has not yet been established. Most tools can describe children's functional ability, participation, or emotional behavior, but few tools can link PMIOD children's behaviors to specific spatial locations or environmental characteristics.

3.3.1. Subjective and proxy reported measures

PMIOD children, especially younger children or children with communication limitations, often rely on parents, caregivers, teachers, therapists, or other professionals as proxy reporters in studies (Hansen et al., 2025). These methods are mainly used to assess children's functional mobility and everyday activities, health related quality of life, emotion regulation and behavioral problems, participation and environmental support, physical pain and fear, and caregiver burden and family adaptation. Children's home participation and environmental support are also often assessed through caregiver questionnaires. For example, YC-PEM can be used to assess children's participation in home

environments and perceived environmental support, while PEDI-CAT can be used to assess functional performance (Albrecht & Khetani, 2017). Studies on family centered services also collect caregivers' perceptions of service processes, professional support, and family participation through parent questionnaires (Almasri et al., 2018; Molinaro et al., 2017; Wang et al., 2015). Health related quality of life is often assessed through caregiver or child reported tools. In addition to PedsQL, CPCHILD has been used to assess health status and quality of life in non-ambulatory children with CP, and validation studies have been conducted in different language versions (Sung et al., 2015, 2020; Zalmstra et al., 2015).

Subjective and proxy reports are also widely used to assess children's emotional, behavioral, and psychological adaptation. CBCL 1.5–5 can be used to measure emotional reactivity, anxiety, depression, somatic complaints, withdrawal, and aggressive behaviors in children. K-PSI can be used to assess parenting stress and child behavioral performance through parent report. CBCL and YSR are validated questionnaires and are commonly used subjective assessment tools in studies of children's emotional and behavioral problems (M. Kim et al., 2025). ERC can assess children's emotion regulation and emotional lability or negativity through parent report, while EMT is an emotion knowledge task completed by children and can complement parent reported tools (Belmonte-Darraz et al., 2021). SDQ can be used to identify behavioral and emotional difficulties in children with SMA, but its formal validation in the SMA population remains limited (Balaji et al., 2026). Tools such as the Developmental Behaviour Checklist have also been used to assess anxiety, social relationship problems, and behavioral manifestations in children with dyskinetic CP (Saini et al., 2025). Pain and fear experiences in children and young people with CP also require understandable and operable specialized tools for assessment (Smith et al., 2025). These tools can help researchers capture anxiety, withdrawal, emotional reactivity, behavioral difficulties, and social relationship problems in PMIOD children (Balaji et al., 2026; Belmonte-Darraz et al., 2021; M. Kim et al., 2025; Saini et al., 2025; Silberg et al., 2016; Smith et al., 2025, 2026). However, caregivers' psychological distress, parenting stress, stigma, and perceived social support may affect their reports of children's emotional and behavioral states (Barfoot et al., 2017; Ma & Mak, 2016; Silberg et al., 2016).

In addition, the Activities Scale for Kids (ASK) is a child self-report tool that allows children to report their everyday activity performance, thereby supplementing the child perspective in assessments mainly based on parental proxy reports (Fabbri et al., 2016). Compared with parent and caregiver reports, child self-report tools are used relatively less often in PMIOD studies. Lindsay (2016) pointed out that related studies often focus on the perspectives of parents and healthcare providers, while children's own views are easily overlooked. The Wheelchair Outcome Measure Young People and the Wheelchair Use Confidence Scale can be used to assess participation satisfaction and confidence in wheelchair use, while the Wheelchair Skills Test focuses more on wheelchair skill performance (Ouellet et al., 2022). APCP-C has also been used to assess activity participation among preschool children with physical disabilities, including play, physical activity, skill development, and social activities (Kang et al., 2017).

Semi structured interviews are an important supplementary method beyond standardized scales. They can present caregivers', children's, parents', and educators' interpretations of autonomy, dependence, comfort, security, participation, and environmental restrictions. Interview methods are often used to capture children's subjective experiences that are difficult to reveal through scales (Bray et al., 2017; Lindsay, 2016), such as children's experiences of lacking autonomy, being pushed, being excluded, or depending on adult assistance during mobility (Bray et al., 2017). Semi structured interviews with caregivers can reveal children's feelings of freedom, control, and empowerment after using ROC (Barchus et al., 2023). Interviews with children and parents can present wheelchair users' understanding of quality of life, independence, and environmental restrictions (Bray et al., 2017). Parent interviews can also be used to understand the quality of interaction between families and professionals in early intervention (Morera-Balaguer et al., 2023). In addition to caregivers and parents, educator interviews can reveal the needs of children with physical disabilities in daycare environments for physical support, adult assistance, and activity participation (Bossi et al., 2021).

3.3.2. Observational and behavioral coding methods

In the included literature, studies on PMIOD children's perceptual and behavioral patterns frequently used video observation, behavioral coding, play coding, activity recording, and interaction coding to analyze children's mobility, play, interaction, and emotional expression. Most studies focused on what children did, how children moved, whom children interacted with, and in which contexts children showed specific behaviors. These observational methods usually recorded children's mobility, play, social interaction, and emotional responses during specific activities through videos, field notes, or contextualized tasks. They can therefore supplement immediate behavioral information that is difficult to capture through questionnaires and proxy reports.

Video recording and behavioral coding were common observational methods in studies of PMIOD children's behavior. Orlando et al. (2025) used active time and sedentary time derived from video coding as reference measures to validate the accuracy of wearable inertial sensors in distinguishing active movement and sedentary time among pre ambulatory children with CP. Video recording can document children's detailed interactions with spaces, devices, peers, and adults over a period of time, thereby helping researchers understand children's activity states and environmental responses more comprehensively (Logan et al., 2017). Logan et al. (Logan et al., 2017) compared play modes, mobility performance, and interactions with peers and adults when children with physical disabilities used forearm crutches or modified ride on cars. Ross et al. (2018) used behavioral coding and Howes' Peer Play Scale in inclusive playgroups to record children's play behaviors and examine whether children with mobility impairments shifted from solitary play to parallel play or peer interaction. Plummer et al. (2021) used field observation to record children's mobility, exploration, and emotional responses when they first used Explorer Mini. However, most of these studies still focused on behavior types and interaction processes, and they did not systematically record the specific spatial locations or movement paths where behaviors occurred. In addition to general video observation, some studies used standardized observation tools to assess parent child interaction. For example, Barfoot et al. (2017) used EASE to code emotional availability between children with CP and their mothers, while Natrasony and Teitelbaum (2016) used NCATS to assess parent child interaction and caregiver responsiveness in gross motor contexts.

Time sampling is also an important method for coding play and activity behaviors in PMIOD children. Partial interval time sampling and momentary time sampling can be used to record children's activity states, play types, and interaction modes within specific time intervals (Orlando et al., 2025). In play coding, Howes' Peer Play Scale has been used as an important coding tool. Researchers used fixed observation intervals to classify children's play states, record changes in play behaviors, and distinguish four types of play behavior (Ross et al., 2018). The distinction between solitary play and parallel play involves the physical distance between children and peers. Therefore, this coding approach can indirectly reflect children's approach, isolation, and interaction relationships during play. However, this approach is still different from the systematic measurement of spatial coordinates, paths, or environmental nodes (Logan et al., 2017; Ross et al., 2018). In this sense, coding can record children's play types and indirectly reflect their approach, isolation, and interaction relationships in space, while time sampling allows researchers to systematically collect activity and interaction information within a relatively short observation period.

Interaction coding can further capture PMIOD children's communication, parent child interaction, peer interaction, and emotional connection. It is mainly used to analyze interaction structures, initiation

behaviors, and response patterns between children and caregivers, peers, teachers, or communication partners. Nijs et al. (2016) included children's positioning and peer directed behaviors in observation coding during group activities, suggesting that children's position can be incorporated as part of behavioral coding. Mutually exclusive coding protocols require researchers to record only one main behavior in each observation interval (Logan et al., 2017). Comparing interactions between children with complex needs and communication partners with and without eye gaze technology is an effective way to capture communication participation supported by assistive technology (Hsieh et al., 2021). Samadani et al. (2021) analyzed neurophysiological synchrony between children with severe physical disabilities and their parents during music therapy, showing that interaction observation and physiological synchrony measurement can supplement traditional behavioral coding. Gijbels et al. (2026) also recorded children's goal directed mobility, delight vocalizations, displeasure vocalizations, and changes in agency during powered mobility intervention. These findings suggest that observation and coding can capture changes in children's active exploration and emotional expression during mobility intervention.

Some studies have also used mixed methods by combining behavioral observation with interviews, scales, or standardized tests. Caregiver interviews have been used to examine children's socioemotional development, sense of freedom, and sense of control after using ride on cars (Barchus et al., 2023). Standardized skill tests have also been used to assess navigation and mobility skills. For example, wheelchair skills training studies combined the Wheelchair Skills Test with measures of participation satisfaction and use confidence to assess children's performance in community mobility (Ouellet et al., 2022). In addition, M. Kim et al. (2025) used behavioral problem scales to assess changes in problem behaviors among children with cerebral palsy during a Snoezelen multisensory environment intervention. This approach helped record behavioral and emotional responses after environmental changes.

Some studies have combined automated data collection tools with traditional observation methods. For example, LENA audio recording systems have been used to automatically quantify children's delight vocalizations, displeasure vocalizations, and parent child conversational turns (Gijbels et al., 2026). Wearable inertial sensors have been combined with video behavioral coding to develop threshold based methods for distinguishing active movement time and sedentary time in children with CP (Orlando et al., 2025). Noldus Observer XT has been used for millisecond level video coding, improving the temporal precision of interaction observation (Hsieh et al., 2021). Samadani et al. (2021) used neurophysiological synchrony indicators to analyze interactions between children with severe physical disabilities and their parents during music therapy. In broader disability research, emotional scenario processing assessment has been used to objectively analyze emotional response patterns in children with attention deficit hyperactivity disorder. Tools such as the Developmental Behaviour Checklist Parent version (DBC-P) and the Child Adjustment and Parent Efficacy Scale Developmental Disability (CAPES-DD) have been used to measure behavioral and emotional problems, including anxiety, self-absorbed problems, and social disturbance (Saini et al., 2025). Overall, observational and behavioral coding methods can record children's mobility, play, communication, and interaction processes in relatively fine detail. However, existing studies still rarely record the specific spatial locations where these behaviors occur.

3.3.3. *Emerging multi-source data and technology assisted methods*

Emerging multisource data and technology assisted methods mainly include wearable sensors, inertial sensors, eye tracking or eye gaze assistive technology, powered mobility device recording, automatic audio recording, and limited physiological measurement. These technological tools can record children's physical activity, communicative interaction, mobility behavior, emotional vocalizations, and physiological responses, thereby supplementing traditional observation and subjective assessment methods.

Physiological indicators have been used in studies of children's emotion regulation and stress responses, including EEG, heart rate variability, and cortisol. However, these studies have mostly used typically developing children or broader developmental disability groups as samples, and direct applications in PMIOD groups remain relatively limited. In music therapy contexts, EEG has been used to analyze neurophysiological synchrony between children with severe physical disabilities and their parents, helping researchers understand emotional connection and interaction between children and caregivers (Samadani et al., 2021). In addition, AR interactive technology has been used in exploratory studies of physical activity interventions for children with developmental disabilities, but this evidence remains small sample technology assisted background evidence (Lin & Chang, 2015).

In physical activity measurement, wearable sensors and inertial sensors can supplement traditional observation methods by recording PMIOD children's activity states and specific movement events. For example, wearable sensors combined with video coding can distinguish active movement time and sedentary time among children with cerebral palsy who have not yet walked independently, thereby improving the objectivity of activity measurement (Orlando et al., 2025). Foot mounted inertial sensors can also automatically identify gait events during children's stair climbing and can be combined with audio feedback to support movement therapy for children with disabilities (Khan & Biddiss, 2017). Sensor technology is often used to measure physical activity levels, movement events, and therapy feedback. However, these data mainly reflect activity time, activity intensity, or movement events. They usually cannot directly indicate children's spatial locations or fully explain the relationship between children's behaviors and specific environmental conditions.

Powered mobility devices (PMD) provide important settings for observing autonomous mobility, environmental exploration, and emotional expression in PMIOD children. Studies have observed toddlers with mobility limitations during initial driving, obstacle avoidance, object approach, and emotional responses when using Explorer Mini (Plummer et al., 2021). Explorer Mini powered mobility intervention has also been combined with LENA audio recording and standardized developmental assessment to analyze changes in children's agency, communication, and social emotional development (Gijbels et al., 2026). In addition, studies of modified ride on cars have shown that powered mobility devices can change children's exploration opportunities, play behaviors, peer interaction, and autonomy experiences (Barchus et al., 2023; Logan et al., 2017; Ross et al., 2018). Therefore, PMD can serve not only as an intervention tool in PMIOD child research but also as a technological platform for observing autonomous exploration, participation behaviors, and positive emotional expression. At the same time, for children with severe motor impairments and complex communication needs, eye gaze assistive technology (EGAT) provides new possibilities for assessing communicative interaction. Comparisons of children's interactions with communication partners with and without EGAT show that eye gaze technology can increase children's communication initiation and information expression while also changing communication partners' interaction patterns (Hsieh et al., 2021).

From the perspective of methodological development, some studies have combined technological tools with observation, standardized assessment, interviews, or manual coding (Hsieh et al., 2021). Wearable sensors are often used in parallel with video behavioral coding to validate children's activity states (Orlando et al., 2025). Powered mobility research has begun to combine device based intervention, standardized developmental assessment, automatic audio recording, and intervention process observation (Gijbels et al., 2026). Caregiver interviews help explain the subjective meanings behind changes in children's autonomy, participation, and socioemotional development (Barchus et al., 2023). In addition, broader disability research has used augmented reality,

visual feedback, and auditory feedback to promote children's physical activity participation (Lin & Chang, 2015). However, this evidence is more often situated in developmental disability or special education contexts, and it cannot be directly equated with evidence on spatial behavior measurement in PMIOD children.

3.3.4. Summary of measurement instruments

Existing studies commonly used standardized scales, proxy reports, behavioral observation, and technology assisted tools to assess functional abilities, participation performance, emotional behaviors, and social interaction in PMIOD children. These methods provide basic data for understanding children's behavioral states, emotional expressions, and subsequent intervention needs. The analysis of the literature database showed that current measurement tools do not focus on only one aspect. Instead, they cover multiple dimensions, including behavioral performance and emotional responses. However, different tools vary in their applicable age ranges, age appropriateness, and physical or behavioral suitability.

Behavioral observation tools mainly cover observation, behavioral coding, activity recording, functional performance, mobility skills, and technology assisted activity measurement. These tools mainly describe what children do, how children move, and how children interact. Behavioral, motor, and participation measurement tools mainly include HPPS (Howes' Peer Play Scale), PTS (Partial interval Time Sampling), Noldus Observer XT 14.0, ALP (Assessment of Learning Powered Mobility), Triaxial Accelerometer, Foot mounted IMU, GMFCS (Gross Motor Function Classification System), GMFM (Gross Motor Function Measure), WST/WST-Q (Wheelchair Skills Test), ASKp/ASK (Activities Scale for Kids), PODCI (Pediatric Outcomes Data Collection Instrument), APCP-C (Assessment of Preschool Children's Participation, Chinese version), YC-PEM (Young Children's Participation and Environment Measure), and PEDI/PEDI-CAT (Pediatric Evaluation of Disability Inventory/Pediatric Evaluation of Disability Inventory Computer Adaptive Test) (Albrecht & Khetani, 2017; Alemdaroğlu-Gürbüz & Karakuş, 2019; Fabbri et al., 2016; Gijbels et al., 2026; Hsieh et al., 2021; Kang et al., 2017; Khan & Biddiss, 2017; Logan et al., 2015, 2017; Orlando et al., 2025; Ouellet et al., 2022; Ross et al., 2018; Valentín-Gudiol et al., 2017). These tools are summarized in Table 8.

Among behavioral observation tools, the adapted Howes' Peer Play Scale and Partial interval Time Sampling have been used for behavioral coding in free play or inclusive play contexts. They are often used to record children's physical activity, play interaction, and object related behaviors (Logan et al., 2017; Ross et al., 2018). GMFCS was used in multiple studies as a standard tool for classifying motor function in children with CP, and it was used for sample description, grouping, or moderator analysis (Balaji et al., 2026; Belmonte-Darraz et al., 2021; M. Kim et al., 2025; Orlando et al., 2025; Ouellet et al., 2022; Saini et al., 2025). Noldus Observer XT 14.0 was used for bidirectional communication coding in children with severe motor and communication impairments, and it can support behavioral coding, statistical analysis, and visualization of interaction sequences (Hsieh et al., 2021). ALP, researcher observation forms, and field notes have been used to record powered mobility learning and initial device use experiences in younger PMIOD children (Gijbels et al., 2026; Plummer et al., 2021). Wearable sensors provide objective tools for measuring activity in PMIOD children (Khan & Biddiss, 2017; Orlando et al., 2025). WST can assess both wheelchair skills and obstacle handling ability (Ouellet et al., 2022). ASKp can be used to assess children's everyday activity and participation performance (Fabbri et al., 2016). PODCI can be used for assessments related to function, pain, and quality of life (Alemdaroğlu-Gürbüz & Karakuş, 2019). APCP-C, YC-PEM, and PEDI/PEDI-CAT series tools have been used to assess participation diversity, environmental support, and functional ability in preschool and younger PMIOD children (Albrecht & Khetani, 2017; Kang et al., 2017). In current studies, behavioral observation systems generally do not have clearly defined age restrictions, but they require trained observers, video coding capacity, and careful consideration of ecological validity in natural environments (Hsieh et al., 2021; Logan et al., 2017; Plummer et al., 2021; Ross et al., 2018). These tools can cover play behavior, physical activity, mobility skills, functional performance, and participation. However, most tools still mainly record behavioral states or functional performance, and they provide limited information about the specific spatial locations, movement paths, and environmental nodes where children's behaviors occur.

The emotional, family, and caregiving environment measurement tools mainly include CBCL (Child Behavior Checklist), SDQ (Strengths and Difficulties Questionnaire), ERC (Emotion Regulation Checklist), EMT (Emotion Matching Task), DBC (Developmental Behavior Checklist), DP-3 (Developmental Profile-3), SBQ (Sleep Behaviour Questionnaire), PedsQL (Pediatric Quality of Life Inventory), CPCHILD/CP QOL

Table 8
Summary of behavioral, motor, and participation measurement tools for PMIOD children.

Tool	Type	Target population	Key features	Application examples
HPPS	Play coding	Preschool children with mobility impairments	Solitary, parallel, peer and adult interaction	Inclusive playgroup coding
PTS	Interval coding	Children with and without disabilities	Physical activity, play and object related behavior	Free play/playgroup coding
Noldus Observer XT	Video coding software	Children with severe motor and communication impairments	Interaction sequence coding, statistics and visualization	EGAT interaction analysis
ALP	Powered mobility assessment	Young children using powered mobility	Powered mobility learning stages	Powered mobility learning observation
Triaxial accelerometer	Wearable sensor	Children with CP or motor impairments	Activity level and intensity	Physical activity recording
Foot-mounted IMU	Wearable sensor	Children with disabilities in stair training tasks	Stair gait events	Movement feedback therapy
GMFCS	Motor classification	Children with CP	Gross motor severity	Sample grouping
GMFM	Motor assessment	Children with CP or motor delay	Gross motor function	Intervention outcome
WST/WST-Q	Wheelchair skill test	Young wheelchair users	Manual/powered wheelchair skills	Wheelchair training outcome
ASKp/ASK	Self-report scale	Children with physical disabilities	Daily activity and participation	Child reported activity assessment
PODCI	Function/QoL scale	Children with physical disabilities	Function, pain and QoL	Functional outcome evaluation
APCP-C	Participation scale	Preschool children with physical disabilities	Participation diversity and intensity	Preschool activity participation
YC-PEM	Participation/environment measure	Young children with functional limitations	Home participation and environment support	Home participation assessment
PEDI/PEDI-CAT	Adaptive function assessment	Children with disabilities	Mobility, daily activities and social function	Functional performance assessment

related tools, WhOM-YP (Wheelchair Outcome Measure – Young People), WheelCon (Wheelchair Use Confidence Scale), 12-GHQ (General Health Questionnaire), K-PSI (Korean Parenting Stress Index), MPOC (Measure of Processes of Care), FES (Family Empowerment Scale), MBPI/FOPQ (Modified Brief Pain Inventory/Fear of Pain Questionnaire), caregiver psychosocial questionnaires, and semi structured interviews (Almasri et al., 2018; An et al., 2019; Balaji et al., 2026; Barchus et al., 2023; Belmonte-Darraz et al., 2021; Bray et al., 2017; M. Kim et al., 2025; Lindsay, 2016; Ma & Mak, 2016; Ouellet et al., 2022; Saini et al., 2025; Silberg et al., 2016; Smith et al., 2025, 2026, Sung et al., 2015, 2020, Zalmstra et al., 2015). These tools are mainly used to assess children's emotional behaviors, quality of life, pain and fear, wheelchair use confidence, caregivers' psychological status, perceptions of family centered services, and subjective experiences. They are summarized in Table 9.

Among emotional and family related measurement tools, CBCL and SDQ are relatively common tools for assessing children's emotional and behavioral problems in the included literature. They have been used in children with CP, SMA, and chronic physical disabilities (Balaji et al., 2026; Belmonte-Darraz et al., 2021; M. Kim et al., 2025; Silberg et al., 2016). ERC mainly measures emotion regulation and emotional lability, while EMT is one of the few emotion knowledge tasks completed by children themselves (Belmonte-Darraz et al., 2021). The combination of DBC, DP-3, and SBQ has been used in children with dyskinetic CP to assess behavioral and emotional problems, developmental profiles, and sleep related performance (Saini et al., 2025). The PedsQL neuromuscular module and CPCHILD/CP QOL related tools have been used for HRQoL assessment in children with specific diagnoses (Balaji et al., 2026; Sung et al., 2015, 2020; Zalmstra et al., 2015). WhOM-YP and WheelCon assess participation satisfaction and use confidence among wheelchair users (Ouellet et al., 2022). 12-GHQ and K-PSI measure caregivers' emotional distress and parenting stress, respectively (M. Kim et al., 2025; Silberg et al., 2016). MPOC is used to assess parents' perceptions of family centered care processes (Almasri et al., 2018). The adapted version of FES has been used to assess changes in family empowerment during collaborative interventions, but its interpretation should consider the limitations of the adapted version (An et al., 2019). CPQ uses caregiver self-report questionnaires to measure caregiving related worry, affiliate stigma, perceived social support, and psychological distress, showing the family caregiving pressure experienced by families of PMIOD children (Ma & Mak, 2016). MBPI and FOPQ focus on pain interference and fear of pain in children and young people with CP (Smith et al., 2025, 2026). Semi structured interviews provide evidence on subjective experiences that scales have difficulty capturing among wheelchair using children, young people with CP, ROC users, and caregivers (Barchus et al., 2023; Bray et al., 2017; Lindsay, 2016).

In addition to category specific tools, some tools can capture both behavioral and emotional dimensions within the same observation context or data collection process. These mixed measurement tools mainly include ROFFN type researcher observation forms (Researcher Observation Form with Field Notes), LENA (LENA Delight/Displeasure Vocalization Classification), and EEG interbrain synchrony measurement (Gijbels et al., 2026; Plummer et al., 2021; Samadani et al., 2021). They are summarized in Table 10.

Among these mixed tools, ROFFN type researcher observation forms have been used to record mobility behavior, environmental exploration, and basic emotional responses during initial Explorer Mini driving contexts (Plummer et al., 2021). LENA has been used to record the language environment, parent child conversational turns, and children's vocalization types, and to distinguish delight, displeasure, and neutral vocalizations (Gijbels et al., 2026). EEG interbrain synchrony measurement captures interaction synchrony between children with severe physical disabilities and their parents at the neurophysiological level,

Table 9
Summary of Emotional, Family, and Caregiving Environment Assessment Tools for PMIOD children.

Tool	Type	Target population	Key features	Application examples
CBCL	Parent report questionnaire	Children with CP or PMIOD	Emotional and behavioral problems	Emotion reactivity and behavioral difficulties
SDQ	Parent/self-report questionnaire	Children with SMA or disabilities	Emotional, conduct, hyperactivity, peer and prosocial problems	Behavioral and emotional difficulties
ERC	Parent report questionnaire	Children including those with CP	Emotion regulation and emotional lability	Emotion regulation assessment
EMT	Child emotion task	School aged children with CP	Emotion knowledge and recognition	Emotional understanding
DBC	Parent report questionnaire	Children with dyskinetic CP	Behavioral and emotional problems	Comorbid behavioral difficulties
DP-3	Developmental assessment	Children with CP	Physical, adaptive, social emotional, cognitive and communication development	Developmental profile
SBQ	Parent report questionnaire	Children with CP	Sleep related problems	Sleep and behavior related assessment
PedsQL	HRQoL questionnaire	Children with SMA or PMIOD conditions	Multidimensional quality of life	Psychosocial health and QoL
CPCHILD/CP QOL related tools	HRQoL questionnaire	Children with CP	Health status, comfort, emotion and QoL	CP related well being
WhOM-YP	Child self-report measure	Young wheelchair users	Participation satisfaction	Wheelchair participation outcome
WheelCon	Self-efficacy scale	Young wheelchair users	Wheelchair use confidence	Mobility confidence
12-GHQ	Caregiver mental health questionnaire	Mothers/caregivers	Emotional distress	Caregiver distress and reporting context
K-PSI	Parenting stress questionnaire	Parents of children with CP	Parenting stress	Family stress assessment
MPOC	Family centered care scale	Parents of children with disabilities	Perceived care process	Family centered care assessment
FES	Family empowerment scale	Families of children with disabilities	Empowerment and decision making	Adapted FES in collaborative intervention
MBPI/FOPQ	Pain and fear assessment tools	Children and young people with CP	Pain interference and fear of pain	Pain and fear assessmen
Caregiver psychosocial questionnaires	Caregiver self-report questionnaires	Caregivers of children with disabilities	Worry, affiliate stigma, social support and distress	Caregiver psychosocial status
Semi-structured interview	Qualitative method	Caregivers, parents, children or wheelchair users	Autonomy, freedom, participation and well being	Subjective experience

Table 10
Summary of mixed behavioral and emotional measurement tools.

Tool	Type	Target Population	Key Features	Application Examples
ROFFN	Researcher observation form with field notes	6-36-month children with mobility impairments	Driving behavior, exploration and basic emotional responses	Initial Explorer Mini use
LENA	Automated audio recording and coding	12–36-month children with motor disabilities	Conversational turns and emotional vocalizations	Explorer Mini powered mobility intervention
EEG	Neurophysiological synchrony measure	Non-speaking children with severe physical disabilities	Measures child–parent interbrain synchrony	Used during music therapy sessions

providing supplementary evidence for understanding parent child emotional connection (Samadani et al., 2021). Overall, mixed measurement tools can supplement traditional questionnaires and observations, but the number of such tools remains small. These tools also have limitations, including high resource demands, high coding training requirements, and insufficient standardization for PMIOD populations.

3.4. Environmental barriers, triggers, and design related evidence

3.4.1. Accessibility, layout, and mobility constraints

During the preschool stage, PMIOD children's interaction with spatial environments is limited in perception, mobility, and behavioral participation. These limitations are related not only to children's physical function but also to conditions for spatial access, path continuity, assistive device fit, and the degree of environmental support (Albrecht & Khetani, 2017; Bray et al., 2017; Ouellet et al., 2024). Existing studies mainly discuss the influence of environmental factors on PMIOD children's mobility and participation through perceived environmental support, assistive mobility device use, play and community participation, and support conditions in school or daycare environments.

Spatial accessibility and mobility conditions are important environmental factors affecting PMIOD children's participation, exploration, and autonomous mobility (Ouellet et al., 2024). The limitations that PMIOD children experience in space come not only from physical function itself but also from whether the environment allows children to enter, move, and participate smoothly. For PMIOD children, opportunities for environmental exploration may be restricted and may further affect mobility experiences, communicative interaction, and socioemotional development (Barchus et al., 2023; Gijbels et al., 2026). Some children with CP may also be affected by perceptual visual dysfunction, which can create additional difficulties in spatial recognition, environmental understanding, and quality of life (Mitry et al., 2016). In real life environments, conditions for spatial access, path continuity, and environmental accessibility can affect PMIOD children's mobility experiences and degree of autonomy. Qualitative studies of children and young people with CP show that transportation or environmental accessibility, safety, and community spatial conditions affect children's everyday participation and social activities (Lindsay, 2016). Wheelchair using children and their families also reported that the absence of ramps, elevators, or accessible paths can prevent children from entering desired spaces and increase their dependence on adult assistance (Bray et al., 2017). In community wheelchair skills training studies, children also reported that environmental conditions such as uneven roads, potholes, and ramps can affect navigational safety and independent mobility (Ouellet et al., 2022).

Assistive mobility devices can expand PMIOD children's range of exploration and participation opportunities to some extent, but the fit between devices and spatial layout is also important. In studies on inclusive playgroups and assistive mobility devices, spatial conditions affected whether children could use devices smoothly to participate in play and interaction (Ross et al., 2018). The same child may show different spatial behavior patterns under different assistive device conditions (Logan et al., 2017; Ross et al., 2018). For example, when a child used a modified ride on car, peer interaction increased, whereas interaction with teachers was more frequent when the child used forearm crutches (Logan et al., 2017). When the environment itself is inaccessible, powered devices may still become new barriers to participation (Barchus et al., 2023). Caregiver interviews by Sloane et al. (2024) also showed that different powered mobility devices vary in convenience, size, turning mode, postural support, and indoor and outdoor use contexts. These factors can affect caregivers' device preferences and children's participation opportunities. When the environment itself is inaccessible, or when device size, turning radius, and postural support do not match the use context, powered devices may still create new barriers to participation (Barchus et al., 2023; Sloane et al., 2024).

In addition to community and play spaces, spatial support conditions in home, school, and daycare environments can also affect PMIOD children's participation. Functional limitations can indirectly affect children's home participation through caregivers' perceptions of environmental supportiveness (Albrecht & Khetani, 2017), indicating that environmental support is not only a physical issue but also involves whether families perceive the space as supporting participation (Albrecht & Khetani, 2017). Some young children with physical disabilities need additional physical support to move between spaces, and educators also believe that environmental arrangement and adult support affect whether children can actively participate in activities (Aguayo et al., 2019; Bossi et al., 2021; Morera-Balaguer et al., 2023; Prakash et al., 2017). Therefore, insufficient spatial support conditions may restrict children's opportunities for active mobility and participation in everyday environments and may also reduce their opportunities to become familiar with spatial structure, path relationships, and environmental feedback through movement.

Some contextual studies further suggest that the quality of physical environments, spatial layout, and inclusive support in preschool and school environments can affect children's participation and well-being. Liao et al. (2025) showed in a study of typically developing preschool children that the Space and Furnishings dimension in ECERS-3 moderated the relationship between inhibitory control and physical fitness, suggesting that the quality of preschool physical environments may affect children's physical activity development. Abyzov et al. (2021) discussed the importance of therapeutic areas, special equipment arrangement, and spatial organization from the perspective of inclusive preschool interior design. Guillemot et al. (2024) showed in a study of school inclusion among students with disabilities that school accommodations and the quality of parent teacher relationships were related to children's subjective well-being and social inclusion. Kang et al. (2017) also showed that children's mobility opportunities in space were related to their level of participation. Assistive devices and environmental support were described by caregivers as factors that can increase children's sense of freedom, sense of control, and opportunities for active exploration, but existing studies still rarely directly examine the effects of specific spatial design variables, such as ramps, corridor width, or furniture layout (Barchus et al., 2023). Overall, most existing studies still understand environmental limitations through caregiver perceptions, interviews, or behavioral observations. They have not directly measured specific spatial variables in homes, such as door width, corridor width, turning radius, furniture layout, or path continuity.

3.4.2. Sensory environmental triggers

In the spatial environments of PMIOD children, sensory environmental factors mainly include visual, auditory, tactile, and multisensory

stimuli. These factors can affect children's attention, sensory processing, comfort, and emotional responses in space (Biddiss et al., 2018; M. Kim et al., 2025; Kos et al., 2026). At present, relatively direct evidence in the literature is mainly concentrated in Snoezelen multisensory environments, multisensory stimulation, music therapy, and technology assisted interactive environments. Direct studies on materials, colors, lighting, acoustic environments, and spatial scale in home spaces remain limited (Abdou & Younis, 2026; Biddiss et al., 2018; M. Kim et al., 2025; Zhu et al., 2025).

First, in studies related to PMIOD children, multisensory environments may affect children's problem behaviors, comfort, and emotional states (Kos et al., 2026). A Snoezelen intervention study in children with cerebral palsy indicated that the sensory room contained elements such as fiber optic lights, bubble tubes, music, tactile panels, aromatherapy, waterbeds, and beanbag chairs (M. Kim et al., 2025). These elements together formed visual, auditory, tactile, and relaxing stimuli. The study showed that after the Snoezelen intervention, emotional reactivity decreased in the experimental group, but not all other dimensions of behavioral problems showed significant changes (M. Kim et al., 2025). In addition, Kos et al. (2026) showed in a study of multisensory stimulation that multisensory foam combined with routine exercise training reduced movement related pain and anxiety in children with CP. Biddiss et al. (2018) showed in a cluster randomized controlled trial of interactive media in rehabilitation waiting spaces that interactive media reduced state anxiety in children and adolescents with disabilities, whereas passive video did not show the same effect. These findings suggest that multisensory stimulation may affect emotional and bodily experiences in PMIOD children, although the relevant evidence mainly comes from clinical or rehabilitation contexts.

Second, auditory and music feedback may also affect children's emotional connection and motivation for participation (Khan & Biddiss, 2017). Samadani et al. (2021) observed neurophysiological synchrony between children with severe physical disabilities and their parents through EEG during music therapy, suggesting that music and interactive environments may promote emotional connection between parents and children (Samadani et al., 2021). The Musical Stairs study also showed that combining auditory feedback with motion detection can improve the participation interest and motivation of children with physical disabilities in stair training (Khan & Biddiss, 2017). These studies indicate that sound is not only a background stimulus but may also become part of action feedback, emotional connection, and participation motivation in children's activity processes.

At the same time, visual and tactile factors in spatial environments may also affect PMIOD children's perception and participation. Perceptual visual dysfunction in children with CP is related to physical impairment and quality of life (Mitry et al., 2016), suggesting that some children may be affected by visual perceptual difficulties in spatial recognition, environmental understanding, and activity participation (Mitry et al., 2016). Studies of typically developing preschool children also show that lighting environments affect children's emotional responses (Zhu et al., 2025). However, because these studies did not focus on PMIOD children, they are more suitable as background evidence for visual environment research. In Snoezelen environments, studies also mentioned that comfortable spaces can be maintained by dimming lights, playing calm music, maintaining appropriate temperature and humidity, and ensuring ventilation (M. Kim et al., 2025). Research on materials, colors, and lighting for PMIOD children remains limited. Existing evidence more often shows that sensory stimulation, physical support, and interactive environments may affect children's participation states (Barchus et al., 2023), but it cannot directly prove the independent effects of specific materials or colors on PMIOD children's spatial exploration (Bossi et al., 2021). Therefore, material and tactile design can be considered potential directions for supporting comfort and participation. Lighting, color, visual stimuli, and spatial atmosphere can also be considered factors that require further exploration in future research on PMIOD spatial environments (Abdou & Younis, 2026).

In addition, some studies have added dynamic visual and auditory feedback to play or rehabilitation environments and reported that these interventions can improve physical activity participation among children with developmental disabilities (Lin & Chang, 2015). However, such studies mostly belong to broader disability or technology assisted background evidence and cannot be directly equated with sensory design evidence in PMIOD children's home spaces. Some architectural and preschool environment studies also discuss the influence of inclusive learning environments on children's emotions and behaviors from the perspectives of visual features, mobility related spatial attributes, safety, and sensory design (Abyzov et al., 2021). However, these studies are mostly based on typically developing preschool children, children with neurodevelopmental disorders, or design analysis, and objective sensory environment measurements for PMIOD children in real residential spaces remain lacking (Abdou & Younis, 2026; Abyzov et al., 2021; Zhu et al., 2025). Overall, existing sensory environment evidence mainly focuses on rehabilitation, experimental, and preschool institutional environments, while direct measurement and systematic analysis of lighting, noise, materials, temperature, and spatial atmosphere inside homes remain limited.

4. Discussion

This review synthesized 176 studies on PMIOD children's perceptual behaviors, emotional responses, spatial experiences, and related research methods in environmental contexts. Overall, existing studies have provided evidence on mobility exploration, play participation, assistive devices, family support, emotional responses, and measurement tools. However, this evidence remains dispersed. Many studies come from rehabilitation, developmental psychology, education, or assistive technology, while studies that directly examine the interaction between PMIOD children and spatial environments remain limited (Alberts et al., 2022; Bray et al., 2017; Logan et al., 2017; Ross et al., 2018; Sloane et al., 2024; Smith et al., 2025, 2026). Returning to this child environment interaction framing, we interpret the synthesized evidence by focusing on how individual mobility ability, caregiving relationships, assistive devices, service support, and physical environmental conditions jointly shape perceptual behaviors and emotional responses. We then discuss how spatial factors appear across different studies and identify current limitations in research methods and measurement tools.

4.1. Synergistic influence of perceptual and emotional variables on spatial experience

Perceptual behaviors and emotional responses should not be treated as independent variables in PMIOD children's spatial experiences. Children's mobility ability, environmental exploration opportunities, adult support, and assistive device use jointly affect their behavioral performance in space and their emotional experiences. Following the logic of ecological systems perspectives and the ICF framework, PMIOD children's spatial experiences need to be understood within the combined context of mobility ability, spatial environments, and caregiving relationships (Aguayo et al., 2019; Albrecht & Khetani, 2017; Bronfenbrenner, 1979; Pan et al., 2015; Prakash et al., 2017; WHO, 2022). Their development and participation are shaped through the combined effects of family, caregivers, assistive devices, service support, and physical environments (Almasri et al., 2018; Mohd Nordin et al., 2019; Pan et al., 2015; Sloane et al., 2024).

First, mobility limitations affect children's opportunities to explore space. For PMIOD children, spatial exploration involves more than the ability to move (Plummer et al., 2021). It also involves whether children can actively approach objects, peers, play areas, or other environmental stimuli (Barchus et al., 2023; Ross et al., 2018; Valentín-Gudiol et al., 2017). When children cannot independently enter spaces, change positions, or approach targets, their opportunities to encounter spatial

structures, path directions, and environmental feedback may decrease (Plummer et al., 2021). Early independent mobility is considered to be related to children's motor, perceptual, cognitive, social, and language development, while PMIOD children's opportunities for environmental exploration are often constrained by physical function and external support conditions (Gijbels et al., 2026). When PMIOD children rely on caregivers for movement over a long period or are restricted to a small activity range because of physical disabilities, their participation is more likely to depend on adult support and may involve experiences of limited autonomy, exclusion, or insufficient social inclusion (Bossi et al., 2021; Bray et al., 2017; Phillips & Hogan, 2015). Assistive mobility devices, modified ride on cars, and powered mobility devices can increase children's mobility opportunities and environmental contact to some extent (Bray et al., 2017; Huang et al., 2022; Plummer et al., 2021). However, whether these opportunities can become stable spatial participation still depends on device fit, spatial conditions, and caregiving support (Barchus et al., 2023; Gijbels et al., 2026; Livingstone & Field, 2021; Logan et al., 2017; Mohd Nordin et al., 2019; Plummer et al., 2021).

These interventions do not mean that children have already gained stable and fully autonomous spatial exploration ability. Whether children can genuinely participate in spatial activities is still affected by device fit, adult supervision, environmental accessibility, passage conditions, and safety conditions (Bray et al., 2017; Lindsay, 2016; Mohd Nordin et al., 2019; Ouellet et al., 2022). These influences are especially evident in play and everyday activity contexts. PMIOD children often need more adult support in play and everyday activities, and their spatial entry, activity transitions, toy approach, and peer approach may all be shaped by adults or environmental conditions (Barchus et al., 2023; Plummer et al., 2021; Ross et al., 2018; Valentín-Gudiol et al., 2017). In studies of inclusive play and assistive devices, different devices produced different interaction patterns rather than consistently increasing or decreasing peer interaction (Logan et al., 2017; Ross et al., 2018). Participation opportunities should also be distinguished from participation quality. Even when children participate in a certain number of activities, their autonomy, depth of interaction, and degree of social inclusion may still differ from those of their peers (Mei et al., 2015; Phillips & Hogan, 2015). Understanding PMIOD children's behavior therefore requires attention to whether children can actively choose, actively approach, actively express, and actively control their spatial actions.

In terms of emotional responses, anxiety, frustration, insecurity, or withdrawal in PMIOD children should not be reduced to individual psychological problems (Adegboye et al., 2017; Smith et al., 2025, 2026). Children's emotional responses are often related to pain, fatigue, bodily unpredictability, spatial inaccessibility, social exclusion, and limited autonomous control (Belmonte-Darraz et al., 2021; Bray et al., 2017; Lindsay, 2016). When children need to continuously rely on adults to push, carry, or decide their movement directions, they may experience a lack of control and may even feel excluded or passively involved (Barchus et al., 2023). In contrast, when children can actively move, approach targets, and participate in play through powered mobility devices or assistive devices, they are more likely to show positive responses such as freedom, sense of control, excitement, smiling, or joyful vocalizations (Barchus et al., 2023; Bray et al., 2017; Gijbels et al., 2026; Logan et al., 2017; Plummer et al., 2021). Action autonomy and environmental controllability in space may therefore be important explanatory clues connecting perceptual behaviors and emotional experiences (Feldner, 2019; Gijbels et al., 2026).

PMIOD children's emotional experiences also need to be understood within the family caregiving environment. Because the emotional states of younger children or children with communication limitations are often obtained through parent or caregiver reports, caregivers' caregiving worries, affiliate stigma, social support, and psychological distress may affect their observation and interpretation of children's emotional and behavioral states (Barutcu et al., 2021; Ma & Mak, 2016; Park & Nam, 2019; Prakash et al., 2017; Silberg et al., 2016). PMIOD children's emotional responses are therefore related to physical limitations, spatial environments, family interaction, caregiving pressure, and reporting sources. Pain and fear are also bodily experiences that cannot be ignored when researchers examine PMIOD children's emotional experiences (Belmonte-Darraz et al., 2021; Kos et al., 2026; Smith et al., 2025, 2026). Adaptation studies of the Modified Brief Pain Inventory and Fear of Pain Questionnaire for children and adolescents with CP suggest that emotional assessment should extend beyond anxiety, withdrawal, or problem behaviors and should also include psychological responses closely related to physical function and bodily sensations (Smith et al., 2025, 2026).

Overall, PMIOD children's perceptual behaviors and emotional responses are interrelated. Mobility limitations may reduce children's exploration and participation opportunities, and restricted exploration and participation may affect children's sense of autonomy, control, and security. Supportive devices, spaces, and interactive environments may provide more opportunities for active exploration and positive emotional expression. However, current evidence mainly comes from observational studies, interviews, small sample interventions, proxy reports, and some clinical intervention studies (Barchus et al., 2023; Bray et al., 2017; Ross et al., 2018). This evidence cannot yet support a stable causal mechanism (Livingstone & Field, 2021; Sloane et al., 2024). It is therefore more appropriate to understand PMIOD children's perceptual behaviors and emotional responses as interrelated dimensions of spatial experience. Future research should further combine real home spaces, children's immediate behaviors, and emotional measurement to examine the specific relationships among spatial conditions, action autonomy, and emotional adaptation.

4.2. Multidimensional interaction of spatial variables

Spatial environmental factors intersect in PMIOD children's perceptual behaviors and emotional responses. Repeatedly mentioned factors include spatial accessibility, path continuity, the fit between assistive devices and spatial layout, multisensory stimulation, material tactility, lighting and visual stimuli, and spatial scale. However, these factors were addressed to different extents across the included studies. Spatial accessibility, mobility paths, and assistive device fit were examined more frequently. Research on materials, colors, lighting, and sensory atmosphere more often came from multisensory environment studies, studies of typically developing children, or broader disability research. Direct evidence from PMIOD children's real home spaces remains limited (Abdou & Younis, 2026; Bray et al., 2017; M. Kim et al., 2025; Ouellet et al., 2022). Current evidence on spatial variables has not been systematically measured within the same research framework. Studies of physical environments more often focus on accessibility, path conditions, device use, and participation opportunities, while studies of sensory environments more often come from Snoezelen environments, multisensory stimulation, music therapy, lighting experiments, or broader disability research. Existing studies have separately suggested that physical and sensory environments may affect children's behaviors and emotions, but few studies have simultaneously measured the relationships among spatial scale, path conditions, light, sound, materials, and children's behavioral responses (Biddiss et al., 2018; Bray et al., 2017; Ouellet et al., 2022; M. Kim et al., 2025). The interaction among spatial variables is therefore a synthesized interpretation of the included studies rather than a mechanism directly examined within a single research framework.

First, spatial accessibility and path conditions were repeatedly examined across the included studies. From the perspective of PMIOD children's perceptual experience, sufficient passage conditions affect whether children can move smoothly, change positions, and participate in activities (Bray et al., 2017; Ouellet et al., 2022). Path continuity and the presence of ramps, elevators, thresholds, or narrow turning areas also affect whether children can move autonomously and enter different spaces (Lindsay, 2016; Ouellet et al., 2022). Morera-Balaguer et al.

(2023) suggested that children's physical support needs and environmental conditions should be considered when understanding their activity participation in early intervention and family support contexts. Other participation studies also show that environmental support is related to children's home participation (Albrecht & Khetani, 2017). Transportation conditions, accessibility facilities, community environments, and indoor passage conditions can affect everyday participation and mobility experiences among children with physical disabilities (Bray et al., 2017; Lindsay, 2016; Ouellet et al., 2022). Spatial accessibility is therefore related to whether children can actively approach targets, change positions, understand paths, and reduce dependence on adult assistance. Accessible support at the physical and material levels may reduce children's dependence and frustration and may improve their sense of autonomous control and security. However, direct measurement evidence on door width, passage scale, turning radius, and internal path conditions in homes remains limited (Ouellet et al., 2022). Overall spatial scale may also be related to PMIOD children's sense of bodily freedom. Wheelchair and powered mobility studies suggest that spatial scale may affect children's turning, approach, and device use, but direct studies of internal home scale, door width, and turning radius remain limited (Barchus et al., 2023; Ouellet et al., 2022; Plummer et al., 2021). This suggests that spatial scale may involve both physical safety and emotional security, but this relationship still needs to be further verified in real home spaces.

Second, the fit between assistive devices and spatial layout also affects PMIOD children's spatial experiences. Assistive devices, wheelchairs, Explorer Mini, and modified ride on cars can expand children's mobility range and increase opportunities for active exploration and participation (Bray et al., 2017; Logan et al., 2017; Ross et al., 2018), but spaces can also constrain the use of these devices (Plummer et al., 2021). Powered mobility devices and modified ride on cars can increase opportunities for environmental exploration, play participation, and peer interaction (Logan et al., 2017; Plummer et al., 2021; Ross et al., 2018). However, when environments are inaccessible, or when device size, turning mode, postural support, and use contexts do not match, assistive devices may not translate into stable autonomous mobility ability (Barchus et al., 2023; Ouellet et al., 2022; Plummer et al., 2021). Assistive devices therefore need to be analyzed together with spatial scale, path organization, and caregiving support. From the perspective of spatial design, research on assistive devices involves the fit of the device itself and whether the space provides sufficient turning, parking, and path conditions for device use (Barchus et al., 2023; Gijbels et al., 2026; Plummer et al., 2021).

Sensory factors such as material tactility, lighting, sound, and color may also affect PMIOD children's comfort, attention, participation, and emotional responses (Abdou & Younis, 2026; Biddiss et al., 2018; Khan & Biddiss, 2017; M. Kim et al., 2025). Although direct evidence on material tactility in PMIOD children's home spaces remains limited, material tactility may affect children's comfort and participation states through continuous bodily contact and sensory feedback. Multisensory environment studies show that combined visual, auditory, tactile, and bodily support stimuli may help reduce problem behaviors in children with cerebral palsy and provide a relatively comfortable and low stress environmental experience (M. Kim et al., 2025). Studies of multisensory foam and interactive media in waiting spaces also suggest that tactile, visual, and interactive feedback may reduce children's anxiety, pain, or state anxiety (Biddiss et al., 2018; Kos et al., 2026), but this evidence mainly comes from rehabilitation or experimental environments rather than home spaces (Biddiss et al., 2018; Kos et al., 2026). Perceptual visual difficulties in children with CP may also be related to physical impairment and quality of life, indicating that visual environments may affect the spatial understanding and participation experiences of some PMIOD children (Mitry et al., 2016). Color and visual cues can be considered potential design directions, but the current literature lacks studies that directly test how color coding affects path recognition or spatial boundary understanding in PMIOD children (Abdou & Younis, 2026; Zhu et al., 2025). Music therapy and sound feedback research also suggests that sound and interactive feedback may be related to children's participation motivation, parent child emotional connection, and training engagement (Khan & Biddiss, 2017; Samadani et al., 2021). These studies cannot be directly equated with evidence on material, color, acoustic environment, or lighting design in PMIOD children's home spaces. Based on current evidence, sensory environmental factors have potential design significance, but they still need to be further verified in real home and everyday activity settings.

The variables repeatedly mentioned in relation to PMIOD children's perceptual behaviors and emotional responses are important intersecting variables affecting their spatial experiences. However, existing evidence cannot support directly translating all spatial factors into fixed design principles. Spatial accessibility, path continuity, and assistive device fit were more frequently examined in the included studies, while direct research on spatial scale, materials, colors, lighting, and tactile stimulation remained limited and mainly indicated areas for future design research (Bray et al., 2017; Ouellet et al., 2022; Abdou & Younis, 2026; M. Kim et al., 2025; Plummer et al., 2021). From the perspective of affordances, spatial variables are not isolated physical parameters. They are transformed into action possibilities through children's physical abilities, assistive devices, and caregiving support (Gibson, 2014/2014). Therefore, spatial design needs to consider accessibility design standards as well as how these variables affect PMIOD children's path use, device fit, sensory responses, caregiver support, and emotional experiences. Future research should translate these design clues into specific variables that can be observed, measured, and compared, so that researchers can explain more clearly how spatial environments affect PMIOD children's behavioral participation, action autonomy, and emotional security.

4.3. Methodological and measurement limitations

Existing tools can assess PMIOD children's developmental status from the perspectives of behavior, emotion, participation, and family support, but their age applicability, disability related suitability, and standardization remain inconsistent (Albrecht & Khetani, 2017; Balaji et al., 2026; Belmonte-Darraz et al., 2021; Saini et al., 2025; Smith et al., 2025, 2026). Among the included environment related studies, only one study directly addressed home residential environments, and it still relied on caregiver perception data (Albrecht & Khetani, 2017). Most studies on PMIOD children's emotional responses still rely mainly on questionnaires, proxy reports, interviews, or researcher observation (Barutcu et al., 2021; Ma & Mak, 2016; Park & Kim, 2020; Park & Nam, 2019). Technology assisted measurement and multisource data integration remain supplementary.

Current methods for assessing PMIOD children's emotional responses are still mainly questionnaire based, descriptive, or proxy reported, which creates clear limitations for young children or children with limited expressive abilities. Although caregiver questionnaire reports are practically necessary, they may be affected by caregivers' emotional states, caregiving stress, affiliate stigma, and levels of social support. Relying on proxy reports alone may overestimate or underestimate children's emotional problems and may therefore fail to fully represent children's immediate emotional experiences (Ma & Mak, 2016; Silberg et al., 2016). Existing tools can assess children's emotional behavior, quality of life, or developmental status from different perspectives, but most tools rely on adult reports, and some tools have not been sufficiently validated in specific PMIOD diagnostic groups. For example, the use of SDQ in children with SMA still requires caution (Balaji et al., 2026; Belmonte-Darraz et al., 2021; Saini et al., 2025). Child observation in some studies also relies mainly on researcher observation records and behavioral coding, so observational findings also need triangulation with other methods (Plummer et al., 2021). In addition, emotional responses closely related to bodily experience, such as pain and fear, require specialized measurement tools that are suitable for the

comprehension and expression abilities of children with CP or PMIOD (Smith et al., 2025, 2026). Children and parents do not always understand quality of life, autonomy, and environmental restrictions in the same way. Differences among child self-reports, parent reports, and interview data should therefore be treated as important research information rather than simply as measurement error (Bray et al., 2017; Lindsay, 2016; Ouellet et al., 2022).

Observation and behavioral coding are also important methods in PMIOD child research, especially for capturing children's immediate responses during mobility, play, device use, peer interaction, and emotional expression (Gijbels et al., 2026; Logan et al., 2017; Plummer et al., 2021; Ross et al., 2018). Compared with subjective reports, observational methods can more directly present children's behavioral performance in specific spatial and activity contexts. However, these methods also have clear limitations. Some studies have short observation periods and highly specific contexts, which makes it difficult for these studies to represent children's real behavioral patterns over longer periods or across multiple settings (Plummer et al., 2021). At the same time, because recruiting PMIOD child samples is difficult, many studies have small sample sizes, and children's behavioral differences across different spaces, devices, and intervention conditions still require further verification (Logan et al., 2017). Existing studies have provided evidence of behavioral changes in play, assistive mobility, and powered mobility interventions, but sample size, intervention contexts, and single group design still limit the generalizability of the findings (Gijbels et al., 2026; Ross et al., 2018). Observation therefore has important value in PMIOD child research, but it is more suitable when combined with interviews, scales, automated data collection tools, and standardized tests to improve the completeness of behavioral interpretation and methodological reliability.

Current studies also do not sufficiently differentiate age groups and children's abilities, which affects fine grained analysis across developmental stages (Gijbels et al., 2026; Ouellet et al., 2022; Plummer et al., 2021; Saini et al., 2025). Many studies analyze children aged 3–6 years or broader age ranges as a whole, but children within the preschool period may differ in physical ability, language expression, emotion regulation, spatial understanding, and autonomous mobility. PMIOD children are not a homogeneous group. Using only GMFCS or a single functional classification may be insufficient for explaining differences in assistive device use, communication ability, and adult support needs (Ouellet et al., 2022; Saini et al., 2025). Children's physical function, assistive device use, and adult support need also vary substantially across individuals. If age and disability severity are not further stratified, research conclusions can easily remain at a broad descriptive level (Hsieh et al., 2021; Ouellet et al., 2022). Future studies should therefore distinguish age stage, disability type, mobility ability, and communication ability more clearly in sample design, rather than using disabled children or young children as uniform labels.

The overall body of research also lacks systematic exploration of PMIOD children's real home spaces (Albrecht & Khetani, 2017; Barchus et al., 2023; Bray et al., 2017; Morera-Balaguer et al., 2023). In the life settings of young children, the home is a core environment. However, many current studies focus on laboratories, rehabilitation centers, schools, daycare settings, or intervention contexts. Studies that directly discuss the interaction between PMIOD children and home spatial environments remain limited. Existing studies have involved home participation, caregiver support, family centered services, and family activity environments, but most of these studies have not systematically measured specific variables in home spaces, such as paths, furniture layout, passage scale, turning space for assistive devices, sensory stimuli, and caregivers' visual supervision (Albrecht & Khetani, 2017; Barchus et al., 2023; Bossi et al., 2021; Bray et al., 2017). This limitation concerns more than research setting. It also means that existing tools mainly measure children's abilities, participation, or caregiver perceptions, while the home space itself is rarely transformed into measurable variables. Although some studies discuss early intervention and the quality of professional support from parents' perspectives, these studies still rarely treat the home space itself as a measurable variable (Morera-Balaguer et al., 2023). Current research on environmental support and home participation therefore still lacks systematic modeling of real home spatial structures, children's movement paths, and spatial intervention pathways.

From a technical perspective, physiological, sensor based, and technology assisted methods are providing new methodological supplements for PMIOD child research. Sensors are suitable for recording activity states and movement events. Eye gaze assistive technology is suitable for analyzing communicative interaction in children with complex needs. Powered mobility devices can provide settings for observing children's autonomous exploration and emotional expression. Automatic audio recording tools such as LENA can capture changes in communication and emotional vocalizations. Physiological indicators such as EEG can also provide supplementary evidence for understanding parent child interaction synchrony and emotional connection. However, most of these methods are still used in small sample, exploratory, or single group intervention studies. They more often support multisource data collection and cross interpretation than an integrated multimodal analysis model (Gijbels et al., 2026; Hsieh et al., 2021; Orlando et al., 2025; Samadani et al., 2021). Sensory processing assessment and feedback studies also suggest that children respond differently to visual, auditory, tactile, and multisensory stimuli. However, this evidence currently comes more often from broader disability or related developmental research, and it still needs to be further translated into real spatial research on PMIOD children.

4.4. Limitations and future work

This review has several limitations.

1) This study was not prospectively registered. The OSF transparency record established during the revision stage was mainly used to document the revised search strategy, database records, eligibility criteria, and data charting framework, and it cannot replace preregistration.
2) This study included only English language articles and reviews, and the search period was limited to January 2015 to May 2026. Therefore, some earlier studies, non-English studies, and gray literature may have been missed.
3) PMIOD was used as a working umbrella term. Although this term helps integrate children with similar mobility limitations and spatial participation needs, heterogeneity still exists across diagnostic types, mobility abilities, communication abilities, and assistive device use statuses.
4) As a scoping review, this study aimed mainly to map the scope of evidence and identify research gaps, rather than to conduct a unified quality appraisal or effect size synthesis for all included studies (Arksey & O'Malley, 2005; Peters et al., 2021; Tricco et al., 2018). Accordingly, the synthesis describes differences in the number, directness, settings, and methods of the available studies rather than grading evidence strength or certainty.

Based on these limitations and current evidence gaps, future research can be developed in four directions. First, researchers should develop standardized measurement tools with clearer structures, more clearly defined scopes of application, and better cross context usability. In particular, the adaptability of tools to different PMIOD child groups needs to be improved (Balaji et al., 2026; Smith et al., 2025, 2026). Second, future studies should combine child self-reports, caregiver reports, behavioral observation, and technology assisted data to reduce dependence on a single proxy report or a single observation result. They should also further explore the synchronization among children's immediate behaviors, emotional expressions, and spatial locations (Samadani et al., 2021; Silberg et al., 2016). Third, future sample

designs should distinguish age stage, disability type, mobility ability, assistive device use status, and communication ability in more detail, in order to strengthen the interpretability of research findings. Fourth, future research should pay more attention to paths, furniture, assistive devices, lighting, sound, materials, and environmental interaction in real home spaces, and should transform these spatial factors into variables that can be observed, measured, and compared as far as possible. Future research also needs to analyze spatial conditions, children's behaviors, emotional responses, and caregiving support together to support subsequent research on PMIOD children's home spaces, early support, and design hypotheses.

Future research also needs to introduce theoretical frameworks such as affordance, ecological systems theory, or the ICF more explicitly, so that spatial variables are no longer treated only as background descriptions but can become analytical units for explaining children's behavioral participation and emotional security. For PMIOD children, whether a space is useable does not depend only on whether the space meets general accessibility standards. It also depends on the fit among children's physical abilities, assistive devices, caregiver support, and sensory environments. Placing these factors within the same research framework can help explain more clearly how home spaces affect children's action autonomy, participation quality, and emotional experiences.

5. Conclusion

Based on 176 studies published between 2015 and 2026, this scoping review summarized PMIOD children's perceptual behaviors, emotional responses, spatial experiences, and related measurement methods. The included literature shows that PMIOD children's everyday spatial use often involves restricted exploration opportunities, obstacle avoidance difficulties, limited action autonomy, and high dependence on adult support and assistive devices. At the emotional level, relevant studies mainly reported anxiety, frustration, insecurity, and participation withdrawal. At the same time, in supportive environments, assistive mobility device use, and positive interaction contexts, children may also show a stronger sense of control, willingness to participate, and positive emotional expression. Existing evidence suggests that PMIOD children's perceptual behaviors and emotional responses should be understood as interrelated dimensions jointly associated with mobility ability, spatial accessibility, assistive devices, caregiver support, and sensory environments.

At the methodological and evidential levels, existing studies still mainly rely on questionnaires, proxy reports, interviews, and researcher observation, while technology assisted measurement and multisource data integration remain supplementary. Spatial accessibility, path continuity, and assistive device fit were more frequently examined, but direct research on materials, colors, lighting, tactile stimulation, and spatial scale in real home spaces remained limited. Future research needs to further differentiate age stages and disability types, combine child self-reports, caregiver reports, behavioral observation, and technology assisted data, and transform home space factors into measurable and comparable analytical variables. Such work can expand the empirical basis for research on PMIOD children's home spaces, design interventions, and early support strategies.

Author's statement on the use of artificial intelligence

This paper was written by three authors. During preparation, we used online tools such as DeepL Translator to translate selected parts of the text and Grammarly to check grammar and improve readability. The authors declare that the scholarly content of this paper was written entirely by the authors and was not generated by large language models. All interpretations, analyses, and conclusions are the authors' own, developed independently following discussion, and the authors take full responsibility for them.

Funding

This research was supported by the China Scholarship Council (CSC) under grant number No. 202308620113.

CRediT authorship contribution statement

Zhouyan He: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Luoqiuzi Fu:** Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Luca Guardigli:** Conceptualization, Project administration, Supervision, Writing – review & editing.

Disclosure of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

References

Abdou, H. M., & Younis, N. A. (2026). Sensory and interactive architectural design strategies for inclusive early childhood learning environments supporting neurodevelopmental diversity. *Architecture, 6*(1), 44–74. https://doi.org/10.3390/architecture6010044

Abyzov, V. A., Balanenko, M. R., & Volynets, T. V. (2021). Features of interior design of inclusive preschool institutions. *Art and Design, 21*(3), 1–29. https://doi.org/10.30857/2617-0272.2021.3.2

Adair, B., Ullenhag, A., Rosenbaum, P., Granlund, M., Keen, D., & Imms, C. (2018). Measures used to quantify participation in childhood disability and their alignment with the family of participation-related constructs: A systematic review. *Developmental Medicine and Child Neurology, 60*(11), 1101–1116. https://doi.org/10.1111/dmcn.13959

Adegboye, D., Sterr, A., Lin, J.-P., & Owen, T. J. (2017). Theory of mind, emotional and social functioning, and motor severity in children and adolescents with dystonic cerebral palsy. *European Journal of Paediatric Neurology, 21*(3), 549–556. https://doi.org/10.1016/j.ejpn.2017.01.013

Adolph, K. E., & Hoch, J. E. (2019). Motor development: Embodied, embedded, enculturated, and enabling. *Annual Review of Psychology, 70*(1), 141–164. https://doi.org/10.1146/annurev-psych-010418-102836

Aguayo, V., Arias, V. B., Verdugo, M.Á., & Amor, A. M. (2019). Measuring support needs in children with motor disability: Validity and utility of the supports intensity scale (SIS-C). *Research in Developmental Disabilities, 95*, Article 103509. https://doi.org/10.1016/j.ridd.2019.103509

Alberts, M., De Ridder, E. A. M., Lodewijks, J. A. J., Pinos Cisneros, T. V., Schoorl, K., Salah, A. A., & Schouten, B. A. M. (2022). Designing a smartphone exergame for children with cerebral palsy in the home environment. *Extended abstracts of the annual symposium on computer-human interaction in play*. https://doi.org/10.1145/3505270.3558325

Albrecht, E. C., & Khetani, M. A. (2017). Environmental impact on young children's participation in home-based activities. *Developmental Medicine and Child Neurology, 59*(4), 388–394. https://doi.org/10.1111/dmcn.13360

Aldrich, N. J., Kenyon, L. K., Lambert, R., Marsman, K., Vasseur, M., Sloane, B., Logan, S. W., & Feldner, H. A. (2025). Quantifying parental perceptions of their experiences with their young children's use of power mobility devices. *Pediatric Physical Therapy, 37*(1), 46–55. https://doi.org/10.1097/PEP.0000000000001158

Aldrich, N. J., Vanderest, D., Slowik, K., Farris, J. P., Zondervan, D. K., & Kenyon, L. K. (2025). Parental perceptions and gender as predictors of changes in children's understanding of how to use a power wheelchair. *Disability and Rehabilitation: Assistive Technology, 20*(8), 2750–2765. https://doi.org/10.1080/17483107.2025.2533510

Alemdaroğlu-Gürbüz, İ., & Karakuş, A. B. (2019). Examining mobility, independence, motor function, participation, and parental stress in a school-aged turkish cerebral palsy population: A cross-sectional study. *Neurological Sciences, 40*(12), 2493–2500. https://doi.org/10.1007/s10072-019-03994-1

Alghamdi, M. S., Chiarello, L. A., Palisano, R. J., McCoy, S. W., Orlin, M., & Abd-Elkafy, E. M. (2020). Longitudinal changes in physical caregiving for parents of children with cerebral palsy. *Physical & Occupational Therapy in Pediatrics, 40*(1), 93–105. https://doi.org/10.1080/01942638.2019.1637386

Almasri, N. A., An, M., & Palisano, R. J. (2018). Parents' perception of receiving family-centered care for their children with physical disabilities: A meta-analysis. *Physical & Occupational Therapy in Pediatrics, 38*(4), 427–443. https://doi.org/10.1080/01942638.2017.1337664

An, M., Palisano, R. J., Yi, C.-H., Chiarello, L. A., Dunst, C. J., & Gracely, E. J. (2019). Effects of a collaborative intervention process on parent empowerment and child performance: A randomized controlled trial. *Physical & Occupational Therapy in Pediatrics, 39*(1), 1–15. https://doi.org/10.1080/01942638.2017.1365324

Anaby, D., Law, M., Coster, W., Bedell, G., Khetani, M., Avery, L., & Teplicky, R. (2014). The mediating role of the environment in explaining participation of children and youth with and without disabilities across home, school, and community. *Archives of*

Physical Medicine and Rehabilitation, 95(5), 908–917. https://doi.org/10.1016/j.apmr.2014.01.005

Anderson, D. I., Campos, J. J., Witherington, D. C., Dahl, A., Rivera, M., He, M. X., Uchiyama, I., & Barbu-Roth, M. (2013). The role of locomotion in psychological development. *Frontiers in Psychology, 4*, 440. https://doi.org/10.3389/fpsyg.2013.00440

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology, 8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Balaji, L., Kariyawasam, D. S., Herbert, K., Sampaio, H. A., Tantsis, E., & Farrar, M. A. (2026). Behavioral and emotional challenges in children with spinal muscular atrophy. *Pediatric Neurology, 175*, 81–87. https://doi.org/10.1016/j.pediatrneurol.2025.10.029

Barchus, R., Barroero, C., Schnare, W., Dean, S. M., & Feldner, H. A. (2023). "Kind of empowered": Perceptions of socio-emotional development in children driving ride-on cars. *Rehabilitation Psychology, 68*(2), 155–163. https://doi.org/10.1037/rep0000482

Barfoot, J., Meredith, P., Ziviani, J., & Whittingham, K. (2017). Parent-child interactions and children with cerebral palsy: An exploratory study investigating emotional availability, functional ability, and parent distress. *Child: Care, Health and Development, 43*(6), 812–822. https://doi.org/10.1111/cch.12493

Barutcu, A., Barutcu, S., Kolkiran, S., & Ozdener, F. (2021). Evaluation of anxiety, depression and burden on caregivers of children with cerebral Palsy. *Developmental Neurorehabilitation, 24*(8), 555–560. https://doi.org/10.1080/17518423.2021.1917718

Belmonte-Darraz, S., Montoro, C. I., Andrade, N. C., Montoya, P., & Riquelme, I. (2021). Alteration of emotion knowledge and its relationship with emotion regulation and psychopathological behavior in children with cerebral palsy. *Journal of Autism and Developmental Disorders, 51*(4), 1238–1248. https://doi.org/10.1007/s10803-020-04605-1

Belmonti, V., Berthoz, A., Cioni, G., Fiori, S., & Guzzetta, A. (2015). Navigation strategies as revealed by error patterns on the magic carpet test in children with cerebral palsy. *Frontiers in Psychology, 6*, 880. https://doi.org/10.3389/fpsyg.2015.00880

Biddiss, E., Knibbe, T. J., Fehlings, D., Mckeever, P., Cohen, A., & Mcpherson, A. (2018). Interactive media as a tool for reducing waiting anxiety at paediatric rehabilitation hospitals: A randomized controlled trial. *Developmental Medicine and Child Neurology, 60*(6), 602–610. https://doi.org/10.1111/dmcn.13646

Black, M. M., Walker, S. P., Fernald, L. C. H., Andersen, C. T., DiGirolamo, A. M., Lu, C. L., McCoy, D. C., Fink, G., Shawar, Y. R., Shiffman, J., Devercelli, A. E., Wodon, Q. T., Vargas-Barón, E., & Grantham-McGregor, S. (2017). Early childhood development coming of age: Science through the life course. *The Lancet, 389*(10064), 77–90. https://doi.org/10.1016/S0140-6736(16)31389-7

Bloemen, M. A. T., Backx, F. J. G., Takken, T., Wittink, H., Benner, J., Mollema, J., & De Groot, J. F. (2015). Factors associated with physical activity in children and adolescents with a physical disability: A systematic review. *Developmental Medicine and Child Neurology, 57*(2), 137–148. https://doi.org/10.1111/dmcn.12624

Bossi, T. J., Rodrigues, A. M., Sehn, A. S., & Piccinini, C. A. (2021). The needs of children with physical disabilities in day care: The perception of educators. *Psicologia em Estudo, 26*, 1–15. https://doi.org/10.4025/psicolestud.v26i0.47006

Bramer, W. M., Rethlefsen, M. L., Kleijnen, J., & Franco, O. H. (2017). Optimal database combinations for literature searches in systematic reviews: A prospective exploratory study. *Systematic Reviews, 6*(1), 245. https://doi.org/10.1186/s13643-017-0644-y

Bray, N., Noyes, J., Harris, N., & Edwards, R. T. (2017). Defining health-related quality of life for young wheelchair users: A qualitative health economics study. *PLoS One, 12*(6), Article e0179269. https://doi.org/10.1371/journal.pone.0179269

Britto, P. R., Lye, S. J., Proulx, K., Yousafzai, A. K., Matthews, S. G., Vaivada, T., Perez-Escamilla, R., Rao, N., Ip, P., Fernald, L. C. H., MacMillan, H., Hanson, M., Wachs, T. D., Yao, H. G., Yoshikawa, H., Cerezo, A., Leckman, J. F., & Bhutta, Z. A. (2017). Nurturing care: Promoting early childhood development. *The Lancet, 389*(10064), 91–102. https://doi.org/10.1016/S0140-6736(16)31390-3

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design* (p. 352). Harvard University Press. https://doi.org/10.2307/j.ctv26071r6. https://www.jstor.org/stable/j.ctv26071r6

Cacioppo, M., Bouvier, S., Bailly, R., Houx, L., Lempereur, M., Mensah-Gourmel, J., Kandalaft, C., Varengue, R., Chatelin, A., Vagnoni, J., Vuillerot, C., Gautheron, V., Dinomais, M., Dheilly, E., Brochard, S., & Pons, C. (2021). Emerging health challenges for children with physical disabilities and their parents during the COVID-19 pandemic: The ECHO french survey. *Annals of Physical and Rehabilitation Medicine, 64*(3), Article 101429. https://doi.org/10.1016/j.rehab.2020.08.001

Campos, J. J., Anderson, D. I., Barbu-Roth, M. A., Hubbard, E. M., Hertenstein, M. J., & Witherington, D. (2000). Travel broadens the mind. *Infancy, 1*(2), 149–219. https://doi.org/10.1207/S15327078IN0102_1

Carmo Rodrigues Almeida, I., Ribeiro, J., & Moreira, A. (2021). Assistive technologies for children with cognitive and/or motor disabilities: Interviews as a means to diagnose the training needs of informal caregivers. *Disability and Rehabilitation: Assistive Technology, 16*(3), 340–349. https://doi.org/10.1080/17483107.2019.1680750

Celik Turan, Z., Kayim, A., Engelen, A.-M., Sezer, K., Dunford, C., & Aki, E. (2025). Parental perspectives on environmental factors affecting participation of children with disabilities: A scoping review to inform inclusive healthcare and support services. *Healthcare, 13*(11), 1282. https://doi.org/10.3390/healthcare13111282

Church, C., Patil, S., Butler, S., Miller, F., Salazar-Torres, J. J., Lennon, N., Shrader, M. W., Donohoe, M., Kalisperis, F., Mackenzie, W. G. S., & Nichols, L. R. (2025). Health-Related quality of life of individuals with physical disabilities in childhood. *Children, 12*(3). https://doi.org/10.3390/children12030365

Colglazier, W. (2015). Sustainable development agenda: 2030. *Science, 349*(6252), 1048–1050. https://doi.org/10.1126/science.aad2333

Di Marino, E., Tremblay, S., Khetani, M., & Anaby, D. (2018). The effect of child, family and environmental factors on the participation of young children with disabilities. *Disability and Health Journal, 11*(1), 36–42. https://doi.org/10.1016/j.dhjo.2017.05.005

Downs, J., Blackmore, A. M., Epstein, A., Skoss, R., Langdon, K., Jacoby, P., Whitehouse, A. J. O., Leonard, H., Rowe, P. W., Glasson, E. J., & The Cerebral Palsy Mental Health Group. (2018). The prevalence of mental health disorders and symptoms in children and adolescents with cerebral palsy: A systematic review and meta-analysis. *Developmental Medicine and Child Neurology, 60*(1), 30–38. https://doi.org/10.1111/dmcn.13555

Eisenberg, N., Spinrad, T. L., & Eggum, N. D. (2010). Emotion-related self-regulation and its relation to children's maladjustment. *Annual Review of Clinical Psychology, 6*(1), 495–525. https://doi.org/10.1146/annurev.clinpsy.121208.131208

Evans-Rogers, D. L., Sweeney, J. K., Holden-Huchton, P., & Mullens, P. A. (2015). Short-term, intensive neurodevelopmental treatment program experiences of parents and their children with disabilities. *Pediatric Physical Therapy, 27*(1), 61–71. https://doi.org/10.1097/pep.0000000000000110

Fabbri, L., Neviani, R., Festini, F., & Costi, S. (2016). Transcultural validation of activities scale for kids (ASK): Translation and pilot test. *Acta BioMedica, 87*, 70–79. https://pubmed.ncbi.nlm.nih.gov/27240035/ (Suppl. 2).

Farran, E., Critten, V., Courbois, Y., Campbell, E., & Messer, D. (2021). Spatial cognition in children with physical disability; what is the impact of restricted independent exploration? *Frontiers in Human Neuroscience, 15*. https://doi.org/10.3389/fnhum.2021.669034

Feldner, H. (2019). Impacts of early powered mobility provision on disability identity: A case study. *Rehabilitation Psychology, 64*(2), 130–145. https://doi.org/10.1037/rep0000259

Gibson, J. J. (2014). *The ecological approach to visual perception* (1st ed.). Psychology Press. https://doi.org/10.4324/9781315740218 (Original work published 1979).

Gijbels, L., Ingraham, K. A., Zaino, N. L., Hoffman, M. E., Mizrahi, J. C., Sinclair, A. N., Woo, B. Y., Fragomeni, A., Meltzoff, A. N., Steele, K. M., Feldner, H. A., & Kuhl, P. K. (2026). Promoting agency and communication through powered mobility: A single-group, repeated measures intervention using the explorer mini in toddlers with motor disabilities. *Frontiers in Rehabilitation Sciences, 6*, Article 1726259. https://doi.org/10.3389/fresc.2025.1726259

Guillemot, F., Lacroix, F., & Nocus, I. (2024). Subjective well-being and social inclusion at school for students with a disability, according to their parents, in France. *Research in Developmental Disabilities, 153*, Article 104814. https://doi.org/10.1016/j.ridd.2024.104814

Hansen, J., Støve, L., Væver, M., & Røhder, K. (2025). Socioith cerebral palsy: A scoping rev-emotional development in young children with cerebral palsy: A scoping review. *Child: Care, Health and Development, 51*(4), Article e70130. https://doi.org/10.1111/cch.70130

Haywood, K. M., & Getchell, N. (2021). *Life span motor development* (Seventh edition). Human Kinetics, ISBN 9780736083928. https://www.vlebooks.com/vleweb/product/openreader?id=none&isbn=9781718210837.

He, Z. Y., Guardigli, L., & Lu, T. H. (2026). User personas and home participation among children with physical mobility impairments: Data-driven behavioral typologies for home adaptation. *Building and Environment, 298*, Article 114646. https://doi.org/10.1016/j.buildenv.2026.114646

Hollin, I. L., Bonilla, B., Bagley, A., & Tucker, C. A. (2022). Social and environmental determinants of health among children with long-term movement impairment. *Frontiers in Rehabilitation Sciences, 3*. https://doi.org/10.3389/fresc.2022.831070

Hoskens, J., Paulussen, S., Goemans, N., Feys, H., De Waele, L., & Klingels, K. (2024). Early motor, cognitive, language, behavioural and social emotional development in infants and young boys with Duchenne muscular dystrophy- a systematic review. *European Journal of Paediatric Neurology, 52*, 29–51. https://doi.org/10.1016/j.ejpn.2024.07.003

Hsieh, Y.-H., Borgestig, M., Gopalarao, D., McGowan, J., Granlund, M., Hwang, A.-W., & Hemmingsson, H. (2021). Communicative interaction with and without eye-gaze technology between children and youths with complex needs and their communication partners. *International Journal of Environmental Research and Public Health, 18*(10), 5134. https://doi.org/10.3390/ijerph18105134

Huang, H.-H. (2018). Perspectives on early power mobility training, motivation, and social participation in young children with motor disabilities. *Frontiers in Psychology, 8*. https://doi.org/10.3389/fpsyg.2017.02330

Huang, H.-H., Chang, C.-H., Tsai, W.-Y., Chu, Y.-W., Lin, M.-C., & Chen, C.-L. (2022). Ride-on cars with different postures and motivation in children with disabilities: A randomized controlled trial. *American Journal of Occupational Therapy, 76*(3), Article 7603205030. https://doi.org/10.5014/ajot.2022.047035

Hwang, A.-W., Liao, H.-F., Granlund, M., Simeonsson, R. J., Kang, L.-J., & Pan, Y.-L. (2014). Linkage of ICF-CY codes with environmental factors in studies of developmental outcomes of infants and toddlers with or at risk for motor delays. *Disability & Rehabilitation, 36*(2), 89–104. https://doi.org/10.3109/09638288.2013.777805

Institute of Medicine National Research Council, I. (2000). In J. P. Shonkof, & D. A. Phillips (Eds.), *From neurons to neighborhoods: The science of early childhood development*. The National Academies Press. https://doi.org/10.17226/9824.

Imms, C., Granlund, M., Wilson, P. H., Steenbergen, B., Rosenbaum, P. L., & Gordon, A. M. (2017). Participation, both a means and an end: A conceptual analysis of processes and outcomes in childhood disability. *Developmental Medicine and Child Neurology, 59*(1), 16–25. https://doi.org/10.1111/dmcn.13237

Imrie, R. (2012). Universalism, universal design and equitable access to the built environment. *Disability & Rehabilitation, 34*(10), 873–882. https://doi.org/10.3109/09638288.2011.624250

Kang, L., Hwang, A., Palisano, R. J., King, G. A., Chiarello, L. A., & Chen, C.-L. (2017). Validation of the chinese version of the assessment of preschool children's participation for children with physical disabilities. *Developmental Neurorehabilitation, 20*(5), 266–273. https://doi.org/10.3109/17518423.2016.1158746

Kao, Y.-C., Orsmond, G. I., Cohn, E. S., & Coster, W. J. (2020). Variables associated with shift of responsibility for daily tasks from parents to children with and without disabilities. *American Journal of Occupational Therapy, 74*(6), Article 7406205070p1. https://doi.org/10.5014/ajot.2020.036764

Kennedy, R. A., Carroll, K., McGinley, J. L., & Paterson, K. L. (2020). Walking and weakness in children: A narrative review of gait and functional ambulation in paediatric neuromuscular disease. *Journal of Foot and Ankle Research, 13*(1), 10. https://doi.org/10.1186/s13047-020-0378-2

Kenyon, L. K., Westman, M., Hefferan, A., McCrary, P., & Baker, B. J. (2017). A home-based body weight supported treadmill training program for children with cerebral palsy: A case series. *Physiotherapy Theory and Practice, 33*(7), 576–585. https://doi.org/10.1080/09593985.2017.1325956

Kesiktas, A. D., Sucuoglu, B., Keceli-Kaysili, B., Akalin, S., Gul, G., & Yildirim, B. (2009). The home environments of young children with and without disabilities. *Infants & Young Children, 22*(3), 201–210. https://doi.org/10.1097/IYC.0b013e3181abe1ae

Khan, A., & Biddiss, E. (2017). Musical stairs: A motivational therapy tool for children with disabilities featuring automated detection of stair-climbing gait events via inertial sensors. *Medical Engineering & Physics, 40*(1), 95–102. https://doi.org/10.1016/j.medengphy.2016.12.009

Khetani, M. A., Graham, J. E., Davies, P. L., Law, M. C., & Simeonsson, R. J. (2015). Psychometric properties of the young children's participation and environment measure. *Archives of Physical Medicine and Rehabilitation, 96*(2), 307–316. https://doi.org/10.1016/j.apmr.2014.09.031

Kim, J. K. (2016). A study on the type of playable furniture for emotional development of preschool children. *Korean Institute of Interior Design Journal, 25*(3), 70–81. https://doi.org/10.14774/JKIID.2016.25.3.070

Kim, M., Yi, S.-H., Lee, J.-S., Lee, J.-Y., Hwang, Y.-T., & Kim, J.-S. (2025). The effect of snoezelen intervention on problem behaviors in children with cerebral palsy: A randomized controlled trial. *Complementary Therapies in Medicine, 89*. https://doi.org/10.1016/j.ctim.2025.103139

Kos, F. M., Arıcıoğlu Sülün, A., & Akdeniz Kudubeş, A. (2026). The effect of multisensory stimulation on exercise related pain and anxiety in children with cerebral palsy: A randomized controlled study. *Journal of Pediatric Nursing, 86*, 614–624. https://doi.org/10.1016/j.pedn.2025.12.014

Law, M., Anaby, D., Teplicky, R., Khetani, M. A., Coster, W., & Bedell, G. (2013). Participation in the home environment among children and youth with and without disabilities. *British Journal of Occupational Therapy, 76*(2), 58–66. https://doi.org/10.4276/030802213X13603244419112

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: Advancing the methodology. *Implementation Science, 5*(1), 69. https://doi.org/10.1186/1748-5908-5-69

Liao, Y., Ji, Y., & Lin, X. (2025). Effects of preschool physical environment and inhibitory control on young children's physical fitness: A hierarchical linear model. *Early Education & Development, 36*(7), 1715–1729. https://doi.org/10.1080/10409289.2025.2496372

Lilian, G. K., Odundo, P. A., Kahiga, R. W., Muriithi, E. M., Mwangi, J., & Koring'ura, J. C. (2016). Teacher sustenance of emotional balance among children aged 4-6 with disability in Kenya: Addressing safety, actualization and independence. *International Journal of Technology and Inclusive Education, Special Issue,* (3)https://doi.org/10.20533/ijtie.2047.0533.2016.0121

Lillo-Navarro, C., Medina-Mirapeix, F., Escolar-Reina, P., Montilla-Herrador, J., Gomez-Arnaldos, F., & Oliveira-Sousa, S. L. (2015). Parents of children with physical disabilities perceive that characteristics of home exercise programs and physiotherapists' teaching styles influence adherence: A qualitative study. *Journal of Physiotherapy, 61*(2), 81–86. https://doi.org/10.1016/j.jphys.2015.02.014

Lin, C.-Y., & Chang, Y.-M. (2015). Interactive augmented reality using scratch 2.0 to improve physical activities for children with developmental disabilities. *Research in Developmental Disabilities, 37*, 1–8. https://doi.org/10.1016/j.ridd.2014.10.016

Lindsay, S. (2016). Child and youth experiences and perspectives of cerebral palsy: A qualitative systematic review. *Child: Care, Health and Development, 42*(2), 153–175. https://doi.org/10.1111/cch.12309

Livingstone, R. W., & Field, D. A. (2021). Exploring young children's activity and participation change following 6 months' power mobility experience. *British Journal of Occupational Therapy, 84*(11), 713–722. https://doi.org/10.1177/0308022620973935

Livingstone, R. W., & Paleg, G. (2014). Practice considerations for the introduction and use of power mobility for children. *Developmental Medicine and Child Neurology, 56*(3), 210–221. https://doi.org/10.1111/dmcn.12245

Logan, S. W., Lobo, M. A., Feldner, H. A., Schreiber, M., MacDonald, M., Winden, H. N., Stoner, T., & Galloway, J. C. (2017). Power-up: Exploration and play in a novel modified ride-on car for standing. *Pediatric Physical Therapy, 29*(1), 30–37. https://doi.org/10.1097/pep.0000000000000336

Logan, S. W., Schreiber, M., Lobo, M., Pritchard, B., George, L., & Galloway, J. C. (2015). Real-world performance: Physical activity, play, and object-related behaviors of toddlers with and without disabilities. *Pediatric Physical Therapy, 27*(4), 433–441. https://doi.org/10.1097/pep.0000000000000181

Ma, G. Y. K., & Mak, W. W. S. (2016). Caregiving-specific worry, affiliate stigma, and perceived social support on psychological distress of caregivers of children with physical disability in Hong Kong. *American Journal of Orthopsychiatry, 86*(4), 436–446. https://doi.org/10.1037/ort0000171

McMahon, J., Harvey, A., Reid, S. M., May, T., & Antolovich, G. (2020). Anxiety in children and adolescents with cerebral palsy. *Journal of Paediatrics and Child Health, 56*(8), 1194–1200. https://doi.org/10.1111/jpc.14879

Mei, C., Reilly, S., Reddihough, D., Mensah, F., Green, J., Pennington, L., & Morgan, A. T. (2015). Activities and participation of children with cerebral palsy: Parent perspectives. *Disability & Rehabilitation, 37*(23), 2164–2173. https://doi.org/10.3109/09638288.2014.999164

Mitry, D., Williams, C., Northstone, K., Akter, A., Jewel, J., Khan, N., Muhit, M., Gilbert, C. E., & Bowman, R. (2016). Perceptual visual dysfunction, physical impairment and quality of life in bangladeshi children with cerebral palsy. *British Journal of Ophthalmology, 100*(9), 1245–1250. https://doi.org/10.1136/bjophthalmol-2015-307296

Mohd Nordin, N. A., Hui Shan, E., & Zanudin, A. (2019). The unmet needs of parents of highly dependent children with cerebral palsy. *International Journal of Environmental Research and Public Health, 16*(24), 5145. https://doi.org/10.3390/ijerph16245145

Molinaro, A., Fedrizzi, E., Calza, S., Pagliano, E., Galli, J., Fazzi, E., Trabacca, A., Vespino, T., Gallino, F., Villani, A., Picciolini, O., Cozzaglio, M., Baranello, G., Zambonin, F., Daniela, F., Mandalari, P., Mirabile, L., Nacinovich, R., Broggi, F., … Di Brina, C. (2017). Family-centred care for children and young people with cerebral palsy: Results from an italian multicenter observational study. *Child: Care, Health and Development, 43*(4), 588–597. https://doi.org/10.1111/cch.12449

Morera-Balaguer, J., Lillo-Navarro, C., De Oliveira-Sousa, S., Montilla-Herrador, J., Escolar-Reina, P., Rodríguez-Nogueira, Ó., & Medina-Mirapeix, F. (2023). Parents of children with disabilities' perceptions regarding the quality of interaction with health professionals working in early intervention: A qualitative descriptive study. *Journal of Clinical Nursing, 32*(17–18), 6519–6532. https://doi.org/10.1111/jocn.16580

Natrasony, C., & Teitelbaum, D. (2016). Watch me move: A program for parents of young children with gross-motor delays. *Physical & Occupational Therapy in Pediatrics, 36*(4), 388–400. https://doi.org/10.1080/01942638.2016.1205163

Nijs, S., Penne, A., Vlaskamp, C., & Maes, B. (2016). Peer interactions among children with profound intellectual and multiple disabilities during group activities. *Journal of Applied Research in Intellectual Disabilities, 29*(4), 366–377. https://doi.org/10.1111/jar.12185

Orlando, J. M., Smith, B. A., Hafer, J. F., Paremski, A., Amodeo, M., Lobo, M. A., & Prosser, L. A. (2025). Physical activity in pre-ambulatory children with cerebral palsy: An exploratory validation study to distinguish active vs. sedentary time using wearable sensors. *Sensors, 25*(4), 1–13. https://doi.org/10.3390/s25041261

Oudgenoeg-Paz, O., & Rivière, J. (2014). Self-locomotion and spatial language and spatial cognition: Insights from typical and atypical development. *Frontiers in Psychology, 5*, 521. https://doi.org/10.3389/fpsyg.2014.00521

Ouellet, B., Berthiaume, J., Fortin, C., Rusu, M. T., Rushton, P. W., Dib, T., Routhier, F., & Best, K. L. (2024). User perceptions about resources based on the wheelchair skills training program for training indoor and community wheelchair skills in pediatrics: A descriptive qualitative study. *Disability and Rehabilitation: Assistive Technology, 19*(7), 2531–2544. https://doi.org/10.1080/17483107.2024.2303464

Ouellet, B., Best, K. L., Wilson, D., & Miller, W. C. (2022). Exploring the influence of a community-based peer-led wheelchair skills training on satisfaction with participation in children and adolescents with cerebral palsy and spina bifida: A pilot study. *International Journal of Environmental Research and Public Health, 19*(19). https://doi.org/10.3390/ijerph191911908

Pan, Y.-L., Hwang, A.-W., Simeonsson, R. J., Lu, L., & Liao, H.-F. (2015). ICF-CY code set for infants with early delay and disabilities (EDD code set) for interdisciplinary assessment: A global experts survey. *Disability & Rehabilitation, 37*(12), 1044–1054. https://doi.org/10.3109/09638288.2014.952454

Park, E.-Y., & Kim, J.-H. (2020). Activity limitation in children with cerebral palsy and parenting stress, depression, and self-esteem: A structural equation model. *Pediatrics International, 62*(4), 459–466. https://doi.org/10.1111/ped.14177

Park, E.-Y., & Nam, S.-J. (2019). Time burden of caring and depression among parents of individuals with cerebral palsy. *Disability & Rehabilitation, 41*(13), 1508–1513. https://doi.org/10.1080/09638288.2018.1432705

Peters, M. D., Godfrey, C., McInerney, P., Munn, Z., Tricco, A. C., & Khalil, H. (2024). *10. Scoping reviews*. JBI Manual for Evidence Synthesis. JBI. https://doi.org/10.46658/JBIMES-24-09. https://synthesismanual.jbi.global

Peters, M. D., Marnie, C., Colquhoun, H., Garritty, C. M., Hempel, S., Horsley, T., Langlois, E. V., Lillie, E., O'Brien, K. K., Tunçalp, Ö., Wilson, M. G., Zarin, W., & Tricco, A. C. (2021). Scoping reviews: Reinforcing and advancing the methodology and application. *Systematic Reviews, 10*(1), 263. https://doi.org/10.1186/s13643-021-01821-3

Phillips, R., & Hogan, A. (2015). Recreational participation and the development of social competence in preschool aged children with disabilities: A cross-sectional study. *Disability & Rehabilitation, 37*(11), 981–989. https://doi.org/10.3109/09638288.2014.949355

Plummer, T., Logan, S. W., & Morress, C. (2021). Explorer mini: Infants' initial experience with a novel pediatric powered mobility device. *Physical & Occupational Therapy in Pediatrics, 41*(2), 192–208. https://doi.org/10.1080/01942638.2020.1819935

Prakash, V., Patel, A. M., Hariohm, K., & Palisano, R. J. (2017). Higher levels of caregiver strain perceived by indian mothers of children and young adults with cerebral palsy who have limited self-mobility. *Physical & Occupational Therapy in Pediatrics, 37*(1), 64–73. https://doi.org/10.3109/01942638.2015.1138016

Ross, S. M., Catena, M., Twardzik, E., Hospodar, C., Cook, E., Ayyagari, A., Inskeep, K., Sloane, B., MacDonald, M., & Logan, S. W. (2018). Feasibility of a modified ride-on car intervention on play behaviors during an inclusive playgroup. *Physical & Occupational Therapy in Pediatrics, 38*(5), 493–509. https://doi.org/10.1080/01942638.2017.1400491

Saini, A. G., Sankhyan, N., Malhi, P., Ahuja, C., Khandelwal, N., & Singhi, P. (2025). Dyskinetic cerebral palsy in children: Clinical perspectives on common comorbidities and health-related quality of life. *Journal of Autism and Developmental Disorders, 55*(10), 3755–3764. https://doi.org/10.1007/s10803-024-06467-3

Samadani, A., Kim, S., Moon, J., Kang, K., & Chau, T. (2021). Neurophysiological synchrony between children with severe physical disabilities and their parents during music therapy. *Frontiers in Neuroscience, 15*, 1–15. https://doi.org/10.3389/fnins.2021.531915

Sigurdardottir, S., Indredavik, M. S., Eiriksdottir, A., Einarsdottir, K., Gudmundsson, H. S., & Vik, T. (2010). Behavioural and emotional symptoms of preschool children with cerebral palsy: A population-based study. *Developmental Medicine and Child Neurology, 52*(11), 1056–1061. https://doi.org/10.1111/j.1469-8749.2010.03698.x

Silberg, T., Brezner, A., Gal, G., Ahonniska-Assa, J., & Levav, M. (2016). The role of maternal distress in the report of behavioral and emotional problems among children with chronic disabilities. *Israel Journal of Psychiatry and Related Sciences, 53*, 17–24.

Sloane, B. M., Kenyon, L. K., Logan, S. W., & Feldner, H. A. (2024). Caregiver perspectives on powered mobility devices and participation for children with cerebral palsy in gross motor function classification system level V. *Developmental Medicine and Child Neurology, 66*(3), 333–343. https://doi.org/10.1111/dmcn.15718

Smith, M. G., Gibson, R. J., Russo, R. N., Smith, N., & Harvey, A. R. (2026). Structural validity of the pain interference questionnaire and fear of pain questionnaire for children and young people with cerebral palsy. *Developmental Medicine and Child Neurology, 68*(5), 661–672. https://doi.org/10.1111/dmcn.70033

Smith, M. G., Gibson, R. J., Schibani, M., Russo, R. N., Thirumanickam, A., & Harvey, A. R. (2025). The comprehensibility and feasibility of the modified brief pain inventory and fear of pain questionnaire adapted for children and young people with cerebral palsy. *Quality of Life Research, 34*(8), 2377–2392. https://doi.org/10.1007/s11136-025-03981-4

Smits, D.-W., Gorter, J. W., Riddell, C. A., Voorman, J. M., Rosenbaum, P. L., Palisano, R. J., Walter, S. D., Hanna, S. E., Van Wely, L., & Ketelaar, M. (2019). Mobility and self-care trajectories for individuals with cerebral palsy (aged 1–21 years): A joint longitudinal analysis of cohort data from the Netherlands and Canada. *The Lancet Child & Adolescent Health, 3*(8), 548–557. https://doi.org/10.1016/s2352-4642(19)30122-1

Ssemata, A. S., Ndekezi, D., Ganshanga, A., & Nalugya, R. (2025). "As time passes, her disability becomes severe." the struggles and challenges of caring for children living with spina bifida and hydrocephalus in Uganda: Perspectives from caregivers. *Disability & Rehabilitation, 47*(26), 6935–6949. https://doi.org/10.1080/09638288.2025.2527947

Stanton, D., Foreman, N., & Wilson, P. N. (1998). Uses of virtual reality in clinical training: Developing the spatial skills of children with mobility impairments. *Studies in Health Technology and Informatics, 58*, 219–232. https://pubmed.ncbi.nlm.nih.gov/10350923/.

Steinfeld, E., & Maisel, J. (2012). *Universal design: Creating inclusive environments*. John Wiley & Sons. https://www.google.it/books/edition/Universal_Design/II6VV5iAW9cC.

Steinhart, S., Kornitzer, E., Baron, A. B., Wever, C., Shoshan, L., & Katz-Leurer, M. (2018). Independence in self-care activities in children with myelomeningocele: Exploring factors based on the international classification of function model. *Disability & Rehabilitation, 40*(1), 62–68. https://doi.org/10.1080/09638288.2016.1243158

Stuart, E., Bird, K., Bhatkal, T., Greenhill, R., Lally, S., Rabinowitz, G., Samman, E., & Sarwar, M. B. (2016). Leaving no one behind: A critical path for the first 1,000 days of the Sustainable Development Goals. *Overseas Development Institute*. https://media.odi.org/documents/10692.pdf.

Sung, K. H., Kwon, S.-S., Cho, G. H., Chung, C. Y., Encisa, C., Menal, H., Narayanan, U. G., & Park, M. S. (2020). Differences in responses to english and korean versions of the caregiver priorities & child health index of life with disabilities (CPCHILD). *Health and Quality of Life Outcomes, 18*(1), 282. https://doi.org/10.1186/s12955-020-01528-4

Sung, K. H., Kwon, S.-S., Narayanan, U. G., Chung, C. Y., Lee, K. M., Lee, S. Y., Lee, D. J., & Park, M. S. (2015). Transcultural adaptation and validation of the korean version of caregiver priorities & child health index of life with disabilities (CPCHILD). *Disability & Rehabilitation, 37*(7), 620–624. https://doi.org/10.3109/09638288.2014.932449

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., … Straus, S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine, 169*(7), 467–473. https://doi.org/10.7326/M18-0850

Ungureanu, A. (2013). Contributions to the psychomotor development of children with motor disabilities from the perspective of their social integration through adapted physical activities. *Journal of Physical Education and Sport, 13*(1), 57–65. https://doi.org/10.7752/jpes.2013.01010

UNICEF. (2017). Early childhood development: For every child, early moments matter. https://www.unicef.org/early-childhood-development. (Accessed 29 June 2020).

UNICEF. (2019). *A world ready to learn: Prioritizing quality early childhood education*. UNICEF. https://www.unicef.org/reports/a-world-ready-to-learn-2019.

UNICEF. (2021). Seen, counted, included: Using data to shed light on the well-being of children with disabilities. https://data.unicef.org/resources/children-with-disabilities-report-2021/.

UNICEF. (2022). *UNICEF fact sheet: Children with disabilities*. United Nations Children's Fund. https://www.unicef.org/documents/factsheet-children-disabilities.

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development (General Assembly Resolution A/RES/70/1)*. United Nations. https://sdgs.un.org/2030agenda.

Valentín-Gudiol, M., Mattern-Baxter, K., Girabent-Farrés, M., Bagur-Calafat, C., Hadders-Algra, M., & Angulo-Barroso, R. M. (2017). Treadmill interventions in children under six years of age at risk of neuromotor delay. *Cochrane Database of Systematic Reviews, 2017*(7), 1–98. https://doi.org/10.1002/14651858.CD009242.pub3

Van Den Heuvel, R. J. F., Lexis, M. A. S., & De Witte, L. P. (2017). Robot ZORA in rehabilitation and special education for children with severe physical disabilities: A pilot study. *International Journal of Rehabilitation Research, 40*(4), 353–359. https://doi.org/10.1097/mrr.0000000000000248

Van Keer, I., Van Leeuwen, K., & Maes, B. (2019). Exploring family activities and child engagement: A study on children with a significant cognitive and motor developmental delay. *Journal of Applied Research in Intellectual Disabilities, 32*(4), 779–791. https://doi.org/10.1111/jar.12568

Wang, M., Petrini, M. A., & Guan, Q. (2015). Evaluation of family-centred services from parents of chinese children with cerebral palsy with the measure of processes of care. *Child: Care, Health and Development, 41*(3), 408–415. https://doi.org/10.1111/cch.12183

Wertlieb, D. (2019). Nurturing care framework for inclusive early childhood development: Opportunities and challenges. *Developmental Medicine and Child Neurology, 61*(11), 1275–1280. https://doi.org/10.1111/dmcn.14234

WHO. (2007). International classification of functioning, disability and health: Children and youth version: ICF-CY. *World Health Organization*. https://iris.who.int/handle/10665/43737.

WHO. (2015). *WHO global disability action plan 2014-2021: Better health for all people with disability*. World Health Organization. WHO Library Cataloguing-in-Publication Data. https://www.who.int/publications/i/item/who-global-disability-action-plan-2014-2021.

WHO. (2022). *Global report on health equity for persons with disabilities*. World Health Organization. https://www.who.int/publications/i/item/9789240063600.

Wilson, P. B., Haegele, J. A., & Zhu, X. (2016). Mobility status as a predictor of obesity, physical activity, and screen time use among children aged 5-11 years in the United States. *The Journal of Pediatrics, 176*, 23–29.e1. https://doi.org/10.1016/j.jpeds.2016.06.016

World Health Organization & United Nations Children's Fund. (2022). *Global report on assistive technology*. World Health Organization. https://www.who.int/publications/i/item/9789240049451.

Yu, C., Wong, E., Gignac, J., Walker, M., & Ross, T. (2024). A scoping review of pediatric healthcare built environment experiences and preferences among children with disabilities and their families. *Herd: Health Environments Research & Design Journal, 17*(2), 309–325. https://doi.org/10.1177/19375867231218035

Zalmstra, T. A. L., Elema, A., Boonstra, A. M., Maathuis, K. G. B., Narayanan, U. G., van der Putten, A. A. J., Reinders-Messelink, H. A., Vlaskamp, C., & Lindeboom, R. (2015). Validation of the caregiver priorities and child health index of life with disabilities (CPCHILD) in a sample of dutch non-ambulatory children with cerebral palsy. *Disability & Rehabilitation, 37*(5), 411–416. https://doi.org/10.3109/09638288.2014.923524

Zhu, Y., Wang, L., Chen, T., Kong, G., & Ma, F. (2025). The impact of lighting on emotional responses in preschool children' s visual environments. *Journal of Building Engineering, 108*, 1–16. https://doi.org/10.1016/j.jobe.2025.112945

Zschorn, M., & Shute, R. (2016). "We are dealing with it the best we can": Exploring parents' attributions regarding their child's physical disability using the "four ws" framework. *Clinical Child Psychology and Psychiatry, 21*(3), 416–431. https://doi.org/10.1177/1359104515614071

Zhouyan He is a PhD student in Architecture and Design at the University of Bologna, Italy. Her research focuses on how home and urban environments support children with mobility impairments, with specific interests in inclusive housing design, environmental psychology, and child-friendly cities.

Luoqiuzi Fu is a PhD candidate at the Institute of Education, University of Lisbon, Portugal. Her research focuses on contemporary issues in education, with a particular interest in art and design teaching processes and the role of educational environments in supporting students' development.

Luca Guardigli is an Associate Professor of Architectural Engineering in the Department of Architecture at the University of Bologna, Italy. His research focuses on technological architectural design, historic building techniques and environmental sustainability, especially in the design and rehabilitation of residential and public buildings.