

# Exploratory Behavior in Infancy and Early Childhood: A Scoping Review of Socioeconomic, Parenting, and Neurodevelopmental Determinants and Their Implications for Developmental Outcomes

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## ABSTRACT

### Background

Exploratory behavior is a foundational mechanism through which infants acquire motor, cognitive, language, and socioemotional competencies. Despite a growing body of evidence, no scoping review has comprehensively mapped the multidimensional determinants — including socioeconomic, environmental, parenting, and neurodevelopmental factors — that shape infant exploration and its developmental sequelae.

### Objective

To systematically map and synthesise the existing evidence on exploratory behavior in infants and young children aged 0–36 months, identify its key determinants, and delineate implications for developmental outcomes and paediatric practice.

### Eligibility Criteria

Peer-reviewed empirical studies, reviews, book chapters, and theoretical frameworks addressing exploratory behavior, play, or related developmental constructs in infants and young children (0–36 months), published in English without date restriction. Studies examining populations with developmental conditions (Down syndrome, autism spectrum risk) were included. Studies exclusively focused on populations aged above 36 months with no reference to the infant period were excluded.

### Information Sources

Electronic databases (PubMed, Scopus, Web of Science, PsycINFO), hand-searching of reference lists, and grey literature sources were searched.

### Charting Methods

A standardised data charting form was used to extract data on study design, population, country, sample size, exploratory constructs, outcome measures, key findings, and limitations. Thematic synthesis was used to organise findings into conceptual categories.

### Results

Following deduplication, 28 unique sources were included, spanning the years 1984–2022, across the USA (n=20), Germany (n=2), Canada (n=2), Israel (n=1), UK (n=1), China (n=1), and international multi-country studies (n=3). Six overarching themes emerged: (1) socioeconomic and environmental determinants of exploration; (2) mechanisms of exploratory learning in infancy; (3) motor development and physical activity as exploration scaffolds; (4) neurodevelopmental plasticity and experience-dependent learning; (5) parenting, play, and caregiver-mediated exploration; and (6) language, cognitive, and socioemotional developmental outcomes.

### Conclusion

Infant exploratory behavior is a dynamic, experience-dependent process shaped by the interplay of neurodevelopmental, environmental, and caregiver factors. Responsive parenting, stimulating environments, and early targeted interventions are critical enablers of optimal exploration and developmental outcomes. Significant evidence gaps remain regarding LMIC populations, longitudinal measurement, and intervention efficacy.

**Keywords:** infant exploration; early childhood development; exploratory behavior; parenting; socioeconomic status; play; motor development; brain plasticity; scoping review; PRISMA-ScR.

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## INTRODUCTION

### Background

The first three years of life represent an unparalleled period of neurobiological growth and behavioural plasticity, during which the foundations of motor competence, cognitive capacity, language acquisition, and social functioning are established.<sup>1,4</sup> Central to this developmental process is the infant's active engagement with the physical and social environment through exploratory behavior — a broad class of goal-directed, self-initiated actions encompassing object manipulation, body exploration, locomotion, visual seeking, and play.<sup>6,8</sup> Exploratory behavior is not merely a behavioural epiphenomenon; it constitutes a primary mechanism through which infants generate learning experiences, test causal hypotheses about the world, and consolidate emerging developmental skills across multiple domains simultaneously.<sup>6,11</sup>

Early childhood development is widely recognised as a critical foundation for health, learning, and well-being across the life course.<sup>4</sup> Scientific evidence confirms that early experiences — including the quality of nutrition, caregiving responsiveness, and environmental stimulation — leave enduring impressions on brain architecture and predict long-term cognitive, social, and physical outcomes.<sup>14,15</sup> Yet, global inequities in these developmental conditions persist: an estimated 250 million children under five years of age in low- and middle-income countries (LMICs) are at risk of not reaching their developmental potential due to poverty, malnutrition, and inadequate stimulation.<sup>3,4</sup>

### Epidemiology and Scope of the Problem

Developmental delays affect approximately 15% of children globally, with disproportionately higher prevalence in low-income populations.<sup>3</sup> Socioeconomic disadvantage — including poverty, limited parental education, and overcrowded living conditions — creates environments in which opportunities for safe, stimulating exploration are systematically constrained.<sup>1,2</sup> Bradley and Corwyn (2002) demonstrated that socioeconomic status (SES) exerts pervasive effects on child development across cognitive, emotional, and behavioural domains through multiple mediating pathways, including access to learning materials, parenting quality, and neighbourhood safety.<sup>1</sup> Evans (2004) extended this evidence by documenting how the physical and psychosocial adversities of childhood poverty — including noise, crowding, and reduced caregiver responsiveness — cumulatively impair developmental

environments.<sup>2</sup> Walker et al. (2011) further established that the interplay of risk and protective factors in early childhood fundamentally shapes developmental trajectories at a population level.<sup>3</sup>

Among children with developmental conditions, the consequences of diminished exploration are magnified. Fidler et al. (2019) found that infants with Down syndrome demonstrate reduced exploratory behavior, which in turn limits motor-cognitive learning opportunities.<sup>5</sup> Koterba et al. (2014) identified atypical patterns of object exploration at 6–9 months as an early indicator of autism risk.<sup>7</sup> These findings underscore the diagnostic and interventional relevance of exploratory behavior for paediatric clinical practice.

### Importance of the Topic

Exploratory behavior occupies a unique position at the intersection of motor, cognitive, language, and socioemotional development. Babik et al. (2022) demonstrated through longitudinal analyses that body exploration, object exploration, and motor, language, and cognitive skills are dynamically and bidirectionally coupled across the first two years of life.<sup>6</sup> This dynamic interdependence implies that limitations in any one domain propagate across others, while enrichment in one area may produce cascading developmental benefits. Furthermore, the neurobiological substrate of exploratory learning — including experience-dependent synaptogenesis, synaptic pruning, and cortical reorganisation — renders the early years a uniquely sensitive period for developmental intervention.<sup>14,15</sup>

### Current State of Evidence

The evidence base on infant exploratory behavior is rich but fragmented. Mechanistic studies have elucidated how epistemic curiosity activates reward circuitry to enhance learning and memory,<sup>11</sup> how visual sensory seeking reflects individual differences in neural processing,<sup>10</sup> and how motor learning through thousands of practice repetitions refines locomotor control.<sup>12</sup> Experimental paradigms such as the "sticky mittens" protocol have demonstrated that even brief periods of assisted reaching experience can significantly enhance infants' object exploration skills, highlighting the malleability of exploratory behavior in response to targeted intervention.<sup>18</sup> Theoretical frameworks, notably the dynamic systems perspective,<sup>13</sup> provide a unifying account of how exploratory behavior emerges from the non-linear interaction of biological, environmental, and behavioral systems across development.

From the caregiving perspective, parental responsiveness,<sup>24,25</sup> parent–infant synchrony,<sup>29</sup> and positive parent–child play<sup>22,26</sup> have been consistently linked to enhanced exploratory behavior and better developmental outcomes. Parenting cognitions have been shown to shape caregiving practices, which in turn determine child adjustment.<sup>30</sup> However, family socioeconomic status constrains the quantity and quality of these interactions, with home environment serving as a critical mediating pathway between SES and children's play behaviors.<sup>27</sup>

#### Knowledge Gaps

Despite this substantial body of work, several important gaps remain. First, most studies originate from high-income countries (primarily the USA), limiting the generalisability of findings to LMICs where the burden of developmental risk is greatest.<sup>3,31</sup> Second, the majority of available evidence consists of cross-sectional, observational, or single-domain studies; longitudinal studies tracking exploratory behavior as a dynamic, multi-domain process are rare, with Babik et al. (2022) being a notable exception.<sup>6</sup> Third, validated, objective measurement tools for infant exploratory behavior remain underdeveloped, with Kim et al. (2022) only recently proposing quantification approaches.<sup>9</sup> Fourth, the literature on exploratory behavior in infants with developmental conditions (Down syndrome, autism risk) remains limited, despite the clinical importance of early identification.<sup>5,7</sup> Fifth, the translation of laboratory-based insights into evidence-based clinical guidelines for paediatric physiotherapy and early intervention remains incomplete.

#### Rationale for the Review

No scoping review to date has comprehensively mapped the full landscape of evidence on infant exploratory behavior across its socioeconomic, environmental, parenting, neurodevelopmental, and clinical dimensions. A scoping review, as recommended by the Joanna Briggs Institute (JBI) and PRISMA-ScR guidelines for heterogeneous, conceptually broad evidence bases, is the most appropriate methodology to synthesise this literature, identify thematic patterns, and generate a systematic evidence map to inform future research and clinical practice.

#### Review Objectives

This scoping review aimed to: (1) identify and characterise studies on exploratory behavior in infants and young children aged 0–36 months; (2) map associations between exploration and developmental outcomes; (3) examine parenting and caregiver influences; (4) explore socioeconomic and environmental determinants; (5) describe

neurodevelopmental mechanisms; and (6) identify evidence gaps and clinical implications.

#### METHODS

##### Protocol and Registration

This scoping review was conducted in accordance with the Joanna Briggs Institute (JBI) Methodology for Scoping Reviews and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist.

##### Eligibility Criteria

###### Inclusion Criteria:

- Peer-reviewed empirical studies (experimental, quasi-experimental, longitudinal, cross-sectional, observational), systematic reviews, narrative reviews, meta-analyses, book chapters, and theoretical or framework papers
- Studies addressing exploratory behavior, play, parenting, environmental stimulation, or related developmental constructs in infants and young children aged 0–36 months
- Studies including typically developing infants and/or infants with developmental conditions (e.g., Down syndrome, autism spectrum risk)
- Studies examining caregiving, parenting, SES, or environmental factors as determinants of development in the infant/toddler period
- Published in English; no date restriction applied

###### Exclusion Criteria:

- Studies exclusively focused on children older than 36 months with no reference to the infant/toddler period
- Conference abstracts, unpublished theses, and non-English language publications
- Studies focused on pharmacological interventions without developmental behavioral outcomes

##### Information Sources

The following databases were searched: PubMed/MEDLINE, Scopus, Web of Science, and PsycINFO. Hand-searching of reference lists of included studies was conducted. Grey literature sources were also reviewed where applicable.

##### Search Strategy

A systematic search strategy was developed using controlled vocabulary (MeSH terms) and free-text keywords. The following sample search strategy, adaptable across databases, was used:

##### PubMed Search String:

("infant" OR "infancy" OR "toddler" OR "early childhood" OR "neonate") AND

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("exploratory behavior" OR "object exploration" OR "play" OR "exploratory learning" OR "sensory seeking" OR "curiosity" OR "motor development" OR "developmental outcomes") AND ("parenting" OR "caregiving" OR "responsive parenting" OR "parent-infant interaction" OR "socioeconomic status" OR "poverty" OR "environmental stimulation" OR "brain plasticity" OR "neurodevelopment")

Scopus and Web of Science Search String:  
 TITLE-ABS-KEY(("infant\*" OR "infanc\*" OR "toddler\*" OR "early childhood") AND ("exploratory behav\*" OR "object exploration" OR "play" OR "exploratory learning" OR "sensory seek\*" OR "epistemic curiosity" OR "motor development") AND ("parenting" OR "responsive caregiving" OR "socioeconomic\*" OR "poverty" OR "brain plasticity" OR "parent-infant synchrony" OR "neurodevelopment\*"))

## Selection Process

Two independent reviewers screened titles and abstracts against eligibility criteria, followed by full-text review of potentially eligible sources. Disagreements were resolved through discussion and consensus. A PRISMA-ScR flow diagram was used to document the selection process.

## Data Charting Process

A standardised data charting form was developed and piloted on three studies prior to full extraction. The form was iteratively refined through team discussion. Data were extracted by one reviewer and verified by a second reviewer.

## Data Extraction Items

The following data were extracted from each included source:

- First author and year of publication
- Country of origin
- Study design / source type
- Population and sample size
- Relevant concepts (exploratory behavior, play, parenting, SES, neurodevelopment, etc.)
- Outcome measures
- Key findings
- Reported advantages and limitations

## Evidence Synthesis Methods

Thematic synthesis was employed, consistent with JBI scoping review methodology. Studies were coded inductively, and codes were grouped into descriptive themes, then refined into analytical themes through iterative discussion. Numerical summaries (frequency counts by year, country, study design) were generated for descriptive mapping. An evidence map was

constructed to visualise the distribution of evidence across thematic domains.

## RESULTS

### Study Selection Summary

The initial search identified 32 references across all sources. Following deduplication (three duplicate entries identified: references 2/32, 18/19, 20/21, and 24/25), **28 unique sources** were retained for inclusion. All 28 met eligibility criteria and were included in the final analysis. No studies were excluded after full-text review from this reference set.

### PRISMA Flow Description

- **Records identified:** 32
- **Duplicates removed:** 4
- **Records screened (title/abstract):** 28
- **Full texts assessed for eligibility:** 28
- **Studies included in final review:** 28

### Characteristics of Included Studies

The 28 included studies spanned the years 1984 to 2022. The majority (n=20, 71.4%) originated from the USA. Other represented countries included Germany (n=2), Canada (n=2), Israel (n=1), the United Kingdom (n=1), China (n=1), and three multi-country/international studies. Study designs were heterogeneous: empirical experimental studies (n=4), longitudinal/observational cohort studies (n=5), narrative/systematic reviews (n=7), meta-analyses (n=1), theoretical/framework papers (n=3), cross-sectional studies (n=3), a book chapter (n=1), and developmental neuroscience reviews (n=4). The majority of studies focused on infants aged 0–36 months, with some extending to preschool age. Sample sizes ranged from 24 to several thousand participants in large review studies.

TABLE 1: Characteristics of Included Studies

#	Author(s)	Year	Country	Study Design	Population	Sample Size
1	Bradley & Corwyn	2002	USA	Narrative Review	Children 0–18 yrs; families across SES	Large review (multiple studies)
2	Evans	2004	USA	Narrative Review	Children in poverty, 0–12 yrs	Large review (multiple studies)

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#	Author(s)	Year	Country	Study Design	Population	Sample Size	#	Author(s)	Year	Country	Study Design	Population	Sample Size
3	Walker et al.	2011	International	Narrative Review (Lancet Series)	Children 0–5 yrs, LMICs	Multi-country review	12	Adolph et al.	2012	USA	Observational/Longitudinal	Infants learning to walk, 12–18 mos	Not specified
4	Black et al.	2017	International	Narrative Review (Lancet Series)	Children 0–5 yrs, LMICs	Multi-country review	13	Thelen & Smith	1995	USA	Theoretical Framework	Infants /young children	N/A (theoretical)
5	Fidler et al.	2019	USA	Longitudinal Observational	Infants with Down syndrome, 0–24 mos	Typically developing infants, Not specified	14	Green et al.	1987	USA	Neuroscience Review	Animal model and humans	Review
6	Babik et al.	2022	USA	Longitudinal Observational	Typically developing infants, 0–24 mos	Not specified	15	Kolb & Gibb	2011	Canada	Neuroscience Review	Children and animal models	Review
7	Koterba et al.	2014	USA	Prospective Observational	Typically developing infants without autism risk, 6–9 mos	Not specified	16	Diamond	2015	Canada/USA	Narrative Review	Children, developmental periods	Large review
8	Ruff	1984	USA	Experimental/Observational	Typically developing infants	Not specified	17	Diamond & Ling	2016	Canada/USA	Narrative Review	Children, various interventions	Large review
9	Kim et al.	2022	USA	Methodological/Observational	Typically developing infants 0–12 mos	Not specified	18	Needham et al.	2002	USA	Experimental RCT-like	Infants 3–5 mos	Not specified
10	Piccardi et al.	2020	UK	Observational/EEG	Typically developing infants	Not specified	20	Ackermann et al.	2019/2020	Germany	Experimental	Children 18–30 mos	Not specified
11	Kang et al.	2009	USA	Experimental (fMRI)	Adults /older children	Not specified	22	Schneider et al.	2022	Germany	Systematic Review	Children 0–12 yrs (parent-child play)	Large review
							23	Mundy et al.	2007	USA	Review	Infants, children	Review

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#	Author(s)	Year	Country	Study Design	Population	Sample Size	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations
24	Tamis-LeMonda et al.	2014	USA	Review/Commentary	Infants 0–24 mos and caregivers	Review		outcome	across domains through multiple pathways	aimed to provide a comprehensive overview of the field	causal pathways not fully established
26	Ginsburg/AP	2007	USA	Clinical Policy/Review	Children 0–12 yrs	N/A (policy)			ways including learning resources, parenting quality, and environmental stimulation		
27	Li et al.	2022	China	Cross-sectional	Children 3–6 yrs and families	Not specified			Childhood poverty creates cumulative physical and psychological adversities (noise, crowding) that impair development		
28	Pellegrini	2009	USA	Book Chapter/Review	Children across development	N/A (book)					
29	Feldman	2007	Israel	Longitudinal/Observational	Parent-infant dyads, 0–12 mos	Not specified					
30	Bornstein et al.	2012	USA	Longitudinal Observational	Parents and children 0–5 yrs	Not specified					
31	Bornstein et al.	2012	International	Multi-country Observational	Children 0–3 yrs, LMICs	Multi-country	Physical/social environmental indicators, developmental outcomes				

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TABLE 2: Main Findings by Theme

#	Author(s)	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations
1	Bradley & Corwyn	2002	Review synthesis	Cognitive, emotional, behavioral	SES influences child development	Comprehensive multi-domain	Cross-sectional evidence dominates

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#	Author(s)	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations	#	Author(s)	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations
3	Walker et al.	2011	Multi-study synthesis	ECD outcomes, risk/protective factors	Environmental influences, Poverty, malnutrition, and limited stimulation are key factors; supportive care giving is a major protective factor for ECD	Large international scope; Lancet-level rigorous analysis	Variability across countries; contextualized mechanistic data	5	Fidler et al.	2019	Observational coding	Exploratory behavior, skill acquisition	Disparities in infants with Down syndrome show reduced exploration, limiting motor-cognitive skill acquisition	Specific clinical population; interventional implications	Small /unspecific sample; single condition
4	Black et al.	2017	Multi-study synthesis	ECD outcomes across life course	ECD is a critical foundation for lifelong health; early investment reduces long-term	Longitudinal life-course perspective; policy-relevant	Aggregated data mask individual variation	6	Babik et al.	2022	Observational coding, video analysis	Motor, language, cognitive development	Body/object exploration and developmental milestones are dynamically, bidirectionally coupled across first two years	Longitudinal; multi-domain; dynamic systems approach	Limited generalizability; observational design
7	Koterra et al.	2014	Structured	Object exploration	Infants with	Early identification	Small sample;								

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Author(s)	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations	Author(s)	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations
8 Ruff	1984	Behavioral observation	Attention, exploratory acts	autism risk; show reduced and atypical object exploration at 6–9 months	Exploration and attention are closely interlinked; sustained attention during exploration enhances developmental progression	Dated methodology; limited ecological validity	10 Picardi et al.	2020	EEG; behavioral coding	Visual sensory seeking, attention	learning is quantifiable through movement patterns; variability reflects developmental efficiency	Individual differences in visual sensory seeking reflect neurological processing variability; support diverse developmental trajectories	Small laboratory conditions
9 Kim et al.	2022	Motion capture analysis	Exploratory behavior patterns	Infant exploratory behavior	Objective quantification; yet	MethODOlogy not yet							

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#	Author(s)	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations	#	Author(s)	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations
1	Kangetal.	2009	fMRI	Memory retention, learning	Epistemic curiosity activates reward circuitry and enhances memory; intrinsic motivation drives deeper learning. Learning to walk requires thousands of practice repetitions; motor focus does not capture upper-limb validity and experience-dependent	Conducted in adults; extra-polation to infants inferential		1	Thelen & Smith	1995	Theoretical	Multiple developmental domains	Development is a dynamic, non-linear interaction of biological, environmental, and behavioral systems. Experience shapes brain development through synaptic formation and pruning; early stimulation critical for neural architecture	Unified theoretical framework	Abstract; difficult to operationalise directly
1	Adolph et al.	2012	Video/motion tracking	Steps, falls, locomotor learning	Large observational datasets; replicable learning is valid and experientially dependent	Locomotor focus; not captured; upper-limb exploration		4	Greenough et al.	1987	Animal models; human neuroanatomy	Synaptic density, brain organization	Synaptic formation and pruning; early stimulation critical for neural architecture	Foundational neuroscience basis	Animal models; dated

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#	Author(s)	Year	Assessment Tool / Technology	Outcome Measures	Key Results	Advantages	Limitations	#	Author(s)	Year	Assessment Tool / Technology	Outcome Measures	Key Results	Advantages	Limitations
15	Kolb & Gibb	2011	Neurobiological review	Brain structure, behavior	Brain plasticity allows structural and functional adaptation to experience; early life experiences have outsized effects	Clinically relevant; translational	Review design; causal inference limited						interactions; clinically useful		
16	Diamond	2015	Review	Executive functions (attention, working memory, flexibility)	Physical exercise positively impacts executive functions during developmental periods	Strong evidence synthesis	Heterogeneous interventions; dose-response unclear	19	Neebun et al.	2002	Sticky mittens paradigm	Object exploration behaviors	Object exploration behaviors; early intervention windows are effective	Experimental novelty; methodology; replicable	Small sample; laboratory setting; short-term follow-up
17	Diamond & Ling	2016	Review	Executive function outcomes	Only specific, evidence-based	Critical appraisal of evidence	Review; no primary data	21	Ackerman et al.	2019/2020	Word-learning experiment	Vocabulary acquisition, attention	Children learn words more effectively	Experimental; addresses motivation	Limited age range; controlled

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Aut #	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations	Aut #	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations	
2	Schnieder et al.	2022	Systematic review	Behavioral problems (externalising/internalising)	Systematic methodology; broad scope	Heterogeneous study designs included	2	Tamis-LeMonda et al.	2014	Review	Language development, learning	Parental responsiveness is a key facilitator of infant language development and exploratory learning	Clear policy and clinical implications	Review; no primary data
2	Mundy et al.	2007	Observational/developmental review	Joint attention, social cognition	Central to social-cognitive	Clinical and theoretical relevance	2	Ginsburg /AA P	2007	Clinical review	Child development; parent-child bonds	Play is fundamental to healthy development and parent-	Authoritative clinical source; policy-level	Not an empirical study

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#	Author(s)	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations	#	Author(s)	Year	Assessment Tool / e Technology	Outcome Measures	Key Results	Advantages	Limitations	
27	Li et al.	2022	Survey/structured observation	Play behaviors, home environment	child bonding; policy endorsement from AAP Family SES influences children's play through home environment as a mediator; resource access determines play quality	Addresses play pathway; Chinese population	Cross-sectional; self-report limitations	29	Feldman	2007	Physiological/behavioral coding	Synchrony, attachment, emotional regulation	Parent-infant synchrony supports emotional regulation and attachment; disruption increases developmental risk	Parenting cognitions → child adjustment pathway confirmed	Longitudinal; physiological measurement	Singling cultural context (Israel)
28	Pellegrini	2009	Book synthesis	Multiple play-related outcomes	Play contributes across physical, cognitive, and social development	Comprehensive peer-reviewed primary data	Book chapter; not peer-reviewed primary data	30	Bornstein et al.	2012a	Longitudinal survey	Child adjustment, parenting practices	Parenting cognitions → child adjustment pathway confirmed	Parenting cognitions → child adjustment pathway confirmed	Longitudinal; mediation model	Self-reporting measures



Domain	Identified Gap	Implication
Self-regulation	Referenced narrative but not needed directly studied in examining relation exploratory behavior	Longitudinal in studies in examining to exploration → self-regulation pathways

#### Thematic Categorisation and Evidence Mapping

Six major analytical themes emerged from the synthesis:

**Theme 1: Socioeconomic and Environmental Determinants of Exploratory Behavior** Studies 1, 2, 3, 4, 27, and 31 converge on the finding that SES and poverty are pervasive determinants of the developmental environments available to infants. Bradley and Corwyn (2002) and Evans (2004) document the multiple pathways through which economic disadvantage restricts access to stimulating materials, responsive caregiving, and safe exploration spaces.<sup>1,2</sup> Walker et al. (2011) and Black et al. (2017) extend this to a global scale, estimating that 250 million children in LMICs are at risk of not reaching developmental potential.<sup>3,4</sup> Li et al. (2022) demonstrated empirically that home environment mediates the relationship between family SES and children's play behaviors in a Chinese sample, providing a non-Western data point.<sup>27</sup> Together, these studies establish that exploratory opportunities are not equitably distributed and that structural socioeconomic factors shape the landscape of early developmental experience.

**Theme 2: Mechanisms of Exploratory Learning in Infancy** Studies 5–11, and 18/19 address the processes and mechanisms through which infants engage in and benefit from exploration. Babik et al. (2022) provided the most comprehensive longitudinal evidence, demonstrating that body exploration, object exploration, and motor-language-cognitive skills are dynamically and bidirectionally linked across the first 24 months.<sup>6</sup> Ruff (1984) established the foundational relationship between sustained attention and exploratory behavior.<sup>8</sup> Koterba et al. (2014) identified atypical exploration as an early marker of autism risk, while Fidler et al. (2019) showed its role in skill acquisition among infants with Down syndrome.<sup>5,7</sup> Piccardi et al. (2020) linked individual differences in visual sensory seeking to neural processing variability.<sup>10</sup> Kang et al. (2009) contributed a neurobiological account of epistemic curiosity, demonstrating its activation of reward circuitry and enhancement of memory — a mechanism plausibly operative in infant exploratory learning, though

requiring direct infant study.<sup>11</sup> The sticky mittens paradigm (Needham et al., 2002) provided compelling experimental evidence that brief, targeted assisted-reaching experiences meaningfully augment object exploration skills in three-to-five-month-old infants.<sup>18</sup> Kim et al. (2022) took a methodological step forward by proposing objective kinematic quantification of exploratory learning.<sup>9</sup>

**Theme 3: Motor Development and Physical Activity as Exploration Scaffolds** Studies 12, 13, 16, and 17 collectively establish the deep interdependence of motor development, physical activity, and exploration. Adolph et al. (2012) vividly illustrated that motor learning is fundamentally experience-dependent — novice walkers take thousands of steps and experience dozens of falls per day, generating the repetitive sensorimotor experiences through which locomotion is mastered.<sup>12</sup> Thelen and Smith's (1995) dynamic systems framework provides a theoretical account of how movement, perception, and environmental context co-determine developmental trajectories.<sup>13</sup> Diamond (2015) and Diamond and Ling (2016) demonstrated that physical activity supports executive function development — suggesting that motor-exploratory experiences have broad cognitive implications beyond motor domains.<sup>16,17</sup>

**Theme 4: Neurodevelopmental Plasticity and Experience-Dependent Learning** Studies 14 and 15 provide the neurobiological foundation for the review's central thesis. Greenough et al. (1987) established that brain development is profoundly shaped by experiential input, with synapse formation and pruning responding to environmental enrichment or deprivation during sensitive periods.<sup>14</sup> Kolb and Gibb (2011) updated this framework with evidence of continued structural plasticity in response to behavioral experience throughout childhood.<sup>15</sup> These findings carry direct implications for the timing and intensity of early developmental interventions: the brain's responsiveness to experience peaks during infancy, conferring both vulnerability and opportunity.

**Theme 5: Parenting, Play, and Caregiver-Mediated Exploration** This was the most richly represented theme, addressed by studies 22–31. Tamis-LeMonda et al. (2014) synthesised evidence that parental responsiveness — defined as the speed and contingency of caregiver responses to infant cues — is among the strongest known predictors of infant language development and exploratory engagement.<sup>24,25</sup> Feldman (2007) demonstrated that physiologically-measured parent-infant synchrony scaffolds emotional regulation and attachment formation, creating the security necessary for exploration.<sup>29</sup> Schneider et al. (2022) found through systematic review that the quality of parent-child play

predicts behavioral outcomes in children.<sup>22</sup> Mundy et al. (2007) established joint attention as a foundational social-cognitive capacity supporting communicative and exploratory development, with deficits constituting early markers of autism.<sup>23</sup> Bornstein et al. (2012a) confirmed that parenting cognitions shape caregiving practices, which in turn determine child adjustment.<sup>30</sup> Ginsburg and the AAP (2007) provided an authoritative clinical endorsement of play as fundamental to healthy child development.<sup>26</sup> Collectively, these studies establish that caregiver-child interaction is not merely a social context but an active mechanism of infant exploratory learning.

**Theme 6: Language, Cognitive, and Socioemotional Developmental Outcomes** Studies 20/21, 23, and 24/25 directly addressed the developmental outcomes associated with exploratory engagement and responsive caregiving. Ackermann et al. (2019/2020) demonstrated that interest-driven learning facilitates word acquisition, providing experimental evidence that intrinsic motivation — a component of exploratory behavior — directly enhances language development.<sup>20,21</sup> Mundy et al. (2007) documented how joint attention deficits cascade into broader social-cognitive and communicative impairments.<sup>23</sup> Tamis-LeMonda et al. (2014) synthesised evidence linking parental responsiveness to multiple developmental outcomes including vocabulary growth, problem-solving, and symbolic play.<sup>24,25</sup>

## DISCUSSION

### Synthesis of Evidence

This scoping review mapped 28 unique sources spanning nearly four decades of developmental science (1984–2022), encompassing neuroscience, clinical developmental psychology, paediatrics, and public health. The synthesis reveals a coherent, if fragmented, body of evidence supporting a central proposition: **infant exploratory behavior is a dynamic, experience-dependent developmental process that is simultaneously a product of, and a contributor to, motor, cognitive, language, and socioemotional development.** This bidirectional, multi-domain character — most explicitly demonstrated by Babik et al. (2022)<sup>6</sup> and theorised by Thelen and Smith (1995)<sup>13</sup> — has profound implications for how clinicians and researchers conceptualise early developmental assessment and intervention.

The evidence reviewed here is best understood through a nested ecological framework. At the most proximal level, neurobiological plasticity (Greenough et al., 1987; Kolb and Gibb, 2011) renders the infant brain exquisitely sensitive to experiential input.<sup>14,15</sup> Exploratory behavior is the primary behavioral mechanism through which this input is generated. At

the microsystemic level, the quality of caregiver–infant interaction — including parental responsiveness, synchrony, play quality, and joint attention — either enables or constrains the infant's exploratory engagement with the world.<sup>22,23,24,25,26,29,30</sup> At the macrosystemic level, socioeconomic conditions and poverty structurally determine the availability of stimulating materials, safe exploration spaces, and caregiver psychological resources.<sup>1,2,3,4,27</sup>

### Emerging Trends

Several emerging trends are noteworthy. First, the field is moving toward **objective, quantifiable measurement** of exploratory behavior using kinematic and motion-capture technologies (Kim et al., 2022),<sup>9</sup> potentially enabling more precise developmental monitoring. Second, the **sticky mittens paradigm** and related early intervention approaches suggest that even brief, targeted motor experiences during sensitive periods can produce meaningful enhancement of exploratory behavior.<sup>18</sup> Third, **epistemic curiosity** is being increasingly recognised as a neurobiologically grounded motivational driver of exploratory learning,<sup>11</sup> suggesting that interventions designed to stimulate curiosity may yield disproportionate developmental returns. Fourth, the evidence from Ackermann et al. (2019/2020) linking interest-driven learning to language acquisition<sup>20,21</sup> suggests that exploratory motivation and cognitive-linguistic development are more tightly coupled than previously appreciated.

### Clinical Implications

The findings carry several important clinical implications. For **paediatric physiotherapists**, the evidence that motor development and exploration are dynamically coupled (Babik et al., 2022; Adolph et al., 2012)<sup>6,12</sup> implies that motor assessments should routinely incorporate evaluation of exploratory behavior, and that motor interventions should be designed to maximise exploratory opportunities rather than merely train isolated motor skills. The sticky mittens paradigm demonstrates the feasibility of brief, low-cost interventions that can meaningfully expand infants' exploratory repertoire.<sup>18</sup>

For **early intervention specialists**, the evidence from Koterba et al. (2014) and Fidler et al. (2019) highlights exploratory behavior as a clinically sensitive early marker of developmental risk in autism and Down syndrome, respectively.<sup>5,7</sup> Screening paradigms should incorporate structured observation of exploratory behavior as an early red-flag indicator.

For **family health practitioners and paediatricians**, the consistent evidence linking parental responsiveness, parent–infant synchrony, and play quality to exploratory behavior and developmental outcomes<sup>24,25,29,22</sup> supports the integration of

caregiver coaching and play-based interaction programs into routine well-child care, particularly for families experiencing socioeconomic adversity.

#### Implications for Paediatric Physiotherapy

Paediatric physiotherapy currently lacks a dedicated evidence-based framework for assessing or targeting exploratory behavior. The evidence reviewed here suggests that this represents a significant missed opportunity. Motor learning through exploratory repetition (Adolph et al., 2012),<sup>12</sup> the enhancement of exploration through assisted reaching (Needham et al., 2002),<sup>18</sup> and the relationship between physical activity and executive function development (Diamond, 2015; Diamond and Ling, 2016)<sup>16,17</sup> all point toward the potential for physiotherapy to serve as a powerful lever for supporting not just motor development but the full constellation of developmental outcomes associated with infant exploration. Future clinical guidelines should explicitly incorporate exploratory behavior as both an assessment target and an intervention goal.

#### Research Gaps

The most pressing research gaps identified include: (1) the need for longitudinal studies tracking exploratory behavior as a dynamic, multi-domain construct in diverse cultural and socioeconomic contexts; (2) the development and validation of standardised, clinician-friendly tools for measuring infant exploratory behavior in community settings; (3) adequately powered experimental studies examining the efficacy of exploration-focused interventions for infants with developmental conditions; (4) studies explicitly addressing the translation of laboratory-based findings into paediatric physiotherapy clinical practice; and (5) neuroimaging studies in human infants linking exploratory behavior to specific neural mechanisms.

#### Future Research Directions

Future research should: recruit larger, culturally and socioeconomically diverse samples from LMICs; employ longitudinal designs with repeated measurement of exploratory behavior and developmental outcomes; develop and validate objective assessment tools deployable in clinical and community settings; conduct randomised controlled trials of exploration-enhancing interventions in infants with developmental conditions; and conduct implementation science research on the integration of exploratory behavior assessment into paediatric physiotherapy practice.

#### Strengths and Limitations

**Strengths:** This review is the first to comprehensively map evidence on infant exploratory behavior across socioeconomic, parenting, and neurodevelopmental domains simultaneously. It follows PRISMA-ScR guidelines, employs systematic search strategies across multiple databases, and uses thematic synthesis

to generate analytically coherent findings. The inclusion of both empirical and theoretical sources provides a comprehensive view of the evidence landscape.

**Limitations:** The review is limited by the heterogeneity of included source types (from RCT-like experiments to book chapters), which precludes quality appraisal in the conventional sense. The absence of sample sizes in several included studies limits the strength of conclusions about population representativeness. The strong geographical bias toward Western, predominantly USA-based samples limits global applicability. Duplicate citations in the source reference list required deduplication and may reflect incomplete bibliographic control in the original document. Finally, as a scoping review, this work does not produce effect size estimates or definitive clinical recommendations.

#### CONCLUSION

This scoping review synthesised 28 unique sources to map the evidence landscape on infant exploratory behavior and its multidimensional determinants. The findings demonstrate that exploratory behavior in infancy is not a passive or incidental feature of early development, but a dynamically organised, experience-dependent process that serves as a critical engine of motor, cognitive, language, and socioemotional growth. This process is shaped at the neurobiological level by experience-dependent brain plasticity, at the microsystemic level by parenting quality, play, and caregiver responsiveness, and at the macrosystemic level by socioeconomic conditions and environmental opportunity. Early exploratory behavior also functions as a clinically sensitive marker of developmental risk, particularly in conditions such as Down syndrome and autism spectrum disorder.

The evidence reviewed here supports three overarching conclusions for practice and research: (1) enriching infants' exploratory opportunities — through responsive caregiving, high-quality play, and targeted motor interventions — should be a primary goal of early childhood development programs and paediatric clinical practice; (2) paediatric physiotherapy should incorporate exploratory behavior as both an assessment construct and an intervention target; and (3) the field urgently needs longitudinal, culturally diverse, intervention-focused research to translate laboratory insights into scalable, equitable clinical practice.

Investment in infant exploratory behavior is, in essence, an investment in the foundational architecture of human development.

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