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Environmental contributions to cognitive development: The role of cognitive stimulation

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Abstract

Early environmental experiences influence children's cognitive and neural development. In particular, cognitive stimulation, defined as environmental inputs that engage the senses and provide learning opportunities for children, fosters acquisition of knowledge across various cognitive domains. Low levels of cognitive stimulation in early life may restrict learning opportunities, contributing to lasting consequences for neural development and later academic and occupational achievement. This review delves into the role of cognitive stimulation in neural development and related cognitive performance, available tools for measuring cognitive stimulation in various settings, and offers insights into future research directions. In addition, variability in cognitive stimulation, often linked to differences in socioeconomic status, may create disparities in children's access to enriching experiences that provide the foundation for learning. We therefore briefly review the role of socioeconomic status in cognitive stimulation and cognitive development. We also leverage evidence from intervention studies to illustrate the importance of cognitive stimulation for children's outcomes. Investigating the influence of cognitive stimulation on children's brain and behavior development is crucial for developing effective intervention strategies to foster the healthy development of all children and unlocking their full potential.

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Declaration of competing interest

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Keywords

Cognitive stimulation; Brain development; Cognitive development; Childhood and adolescence; Environment

Introduction

Children are profoundly influenced by their early environment. Understanding how environmental experiences shape cognitive and neural development is a critical goal of developmental science. Cognitive stimulation has been increasingly recognized as a key aspect of environmental experience linked to children's neurocognitive development. It refers to the availability of enriching environmental inputs that facilitate learning opportunities for children (Christensen et al., 2014; Hackman et al., 2010; Rosen et al., 2019). A cognitively stimulating environment engages different senses and includes social interactions that foster the acquisition of knowledge. While cognitive stimulation may involve independent exploration, for human infants and young children, it often involves engagement with an adult who can provide learning opportunities and guide attention, allowing a child to explore the world, learn from experience, and move toward independence (Vygotsty, 1978). These experiences promote cognitive development across numerous domains, including language ability, executive function, and planning (Daneri et al., 2019; Hackman et al., 2015; Rosen et al., 2020). Low levels of cognitive stimulation early in development can constrain learning opportunities and have lasting consequences for neural development and later academic and occupational achievement. It is important to note that here we define cognitive stimulation as not simply the inverse of psychosocial neglect. Psychosocial neglect pertains to inadequate social and emotional stimulation or support. It involves a lack of adequate social interaction, emotional care, or nurturing environments, leading to emotional, social, and sometimes cognitive stagnation or underdevelopment. Psychosocial neglect involves a broader context of emotional and social deprivation, which can impact cognitive development, while cognitive stimulation specifically refers to activities, interactions, or environments that facilitate learning opportunities for an individual and is agnostic about the emotional aspects of that stimulation.

In this narrative review, we discuss the role of cognitive stimulation in brain and cognitive development and describe current tools to measure cognitive stimulation in the home and other settings. We also argue that cognitive stimulation can be studied both directly and indirectly, through different modes (i.e., caregiver-mediated and non-caregiver mediated) and in different contexts (i.e., inside the home, in school, in the broader community). Measuring cognitive stimulation across these dimensions will facilitate a deeper understanding of the types of exposures and experiences that promote cognitive development in children and how different dimensions of stimulation interact with one another. The aim of this paper is threefold: firstly, the paper reviews the evidence on the role of cognitive stimulation in neurocognitive development. Secondly, it provides researchers with an overview of existing tools for studying cognitive stimulation, both directly and indirectly, across various contexts. Thirdly, it serves as a call to action for the development

of new measures in this field. Together, we hope this piece will provide a comprehensive understanding of how cognitive stimulation is associated with cognitive development.

Cognitive stimulation in the home environment

In the home, cognitive stimulation includes caregiver-involvement in learning, access to developmentally appropriate learning materials and toys, variety of learning experiences, opportunities for independent engagement, and a complex linguistic environment (Hackman et al., 2010; Hackman & Farah, 2009; Rosen et al., 2019). Low levels of cognitive stimulation involve fewer opportunities for learning, less enriched learning experiences, and lower caregiver-involvement in learning. While both caregiver-mediated learning (i.e., where the caregiver scaffolds situations to make it possible for the child to learn and responds appropriately when a child is struggling) and enriching materials contribute to cognitive stimulation, we have previously suggested that direct caregiver involvement may be the most crucial (Rosen et al., 2019). Activities such as reading to children, assisting them in learning letters, numbers, names of objects, and engaging them through play and other activities have a significant impact on early learning (Ma et al., 2016; Sénéchal & LeFevre, 2002). One possibility is that having only learning materials in the absence of adult engagement may not be sufficient to support learning. While limited access to developmentally appropriate learning materials may limit learning opportunities for children, this can be mitigated by an adult creatively using the environment to guide children's learning (e.g., an adult who calls out the names of objects in everyday life or who guides learning about math and numbers through everyday tasks such as cooking).

It is important to note that over-involvement, like intervening when they're facing mild difficulties or steering their focus towards what adults deem important while the child is independently engaged in learning, are likely to have negative consequences on their overall growth and self-directed learning (King et al., 2023). Research shows that children are much less likely to persist in a difficult task if an adult takes over (Leonard et al., 2021) and caregiver intrusiveness is associated with lower self-regulation in children (Obradović et al., 2021). Therefore, it is critical to emphasize that cognitive stimulation is about scaffolding (i.e., guiding and supporting a child's learning to foster independence), providing opportunities for children to explore, guiding learning when needed, but also responding to the child's specific needs.

Cognitive stimulation beyond the parent–child dyad

It is undeniable that the parent–child relationship plays a key role in shaping development. However, children live in complex social and ecological environments (Bronfenbrenner, 1994) and are likely to encounter many other sources of cognitive stimulation both within and outside their homes. Indeed, the importance of early childcare and educational settings in children's cognitive and socioemotional development is well established (Duncan & National Institute of Child Health and Human Development Early Child Care Research Network, 2003; Phillips & Lowenstein, 2011). Yet, existing studies aimed at examining the role of cognitive stimulation specifically have primarily assessed home-based cognitive stimulation and often from a *parent-centric* perspective. For example, a widely used

approach involves asking parents, "How many days each week do *you* read children's books to your child?"(Cates et al., 2023) rather than examining what the child experiences regardless of who is providing the stimulation (e.g., "How many days each week is *your child read to at home, at school, or in your community?*"). Further, some metrics ask researchers to identify only one primary caregiver in the home and exclude cognitive stimulation coming from other sources (even within the home) (Cates et al., 2023). We argue that it is important to consider the environment *from the vantage point of a given child* rather than from that of the child's caregiver (s). For example, alloparenting is a common caregiving style worldwide, where the care of most children is shared among multiple individuals, such as grandparents, siblings, and other members of the community (Keller, 2016). In such a context, the type of cognitive stimulation the child receives depends on a much larger group of caregivers that extends far beyond the primary caregiving parent. Current methods may lose important information about cognitive stimulation experienced by a child in such a context. Further, there has been a significant increase in the proportion of children who are enrolled in early childhood education and care (ECEC) facilities in many developed nations as workforce participation by women has accelerated in these countries. ECEC centers can serve as important platforms to support children's learning and school readiness. Indeed, research indicates that attending ECEC promotes cognitive abilities, which could indicate that cognitively enriching experiences in these environments are impactful (Burger, 2010; Stahl et al., 2018).

In addition, as children grow older, they spend less time at home and more time in the broader community (L. Larson et al., 2011), where they are exposed to many other influences, such as peers, neighbors, and school environments. All these factors may provide important sources of cognitive stimulation during childhood and adolescence. For example, the school environment can play an important role in shaping children's learning opportunities through interactions with teachers and other adults (Vandenbroucke et al., 2018) and availability of extra-curricular activities (Marsh & Kleitman, 2002). Indeed, seminal work by Crosnoe and colleagues showed that stimulation in the home context is the first, but not the only, ingredient in early learning and highlighted the importance of childcare, and school settings (Crosnoe et al., 2010). However, cognitive stimulation outside the parent–child dyad remains under-explored in the literature. In subsequent sections we discuss the importance of cognitive stimulation for children's brain and behavior development as well as review current methods to assess cognitive stimulation across different contexts.

Cognitive stimulation and neurocognitive development

Cognitive stimulation plays a critical role in the development of children's cognitive development including executive function, language, and academic achievement. Below, we review literature showing that children who receive high levels of cognitive stimulation tend to perform better on tests of executive function, general cognitive ability, language development, and academic achievement. In addition, while research in this area is in its nascent stages, we outline the neural mechanisms that may underlie the association of cognitive stimulation with these outcomes.

Cognitive stimulation and cognitive function

Executive functions are a set of cognitive skills critical for goal-directed behavior that are strongly correlated with academic achievement (Blair & Razza, 2007; Samuels et al., 2016). Higher cognitive stimulation in the home is associated with higher scores on executive function tasks, including working memory, inhibitory control, cognitive flexibility, and planning (e.g., Hackman et al., 2015; Koşkulu-Sancar et al., 2023; Rosen et al., 2020; Sarsour et al., 2011). Additionally, cognitive stimulation is associated with growth in executive function over time in school aged children, such that children raised in homes with higher cognitive stimulation show greater improvements in executive function from ages five to seven years (Rosen et al., 2020). In contrast, children raised in institutional settings with profoundly limited cognitive stimulation have been shown to exhibit lower executive function than their family-reared counterparts (Bos et al., 2009). However, it is important to note that institutional rearing is often characterized by profound deprivation in many dimensions beyond just cognitive stimulation. Children raised in institutions also experience psychosocial neglect along with rotating shift-based staff members providing care often pose challenges for the development of secure attachments. Therefore, while cognitive stimulation is lacking in these environments, it is uncertain whether it alone accounts for differences in executive functioning.

Parental scaffolding is a robust predictor of executive function (Bibok et al., 2009; Lengua et al., 2007, 2014). Longitudinal work has demonstrated the notable positive influence of family-based cognitive stimulation during preschool years on enhancing cognitive outcomes (broadly speaking) in children during their school-aged years (Xiong et al., 2020). A recent *meta*-analysis found positive associations between cognitive stimulation in the home with general cognitive abilities and nonverbal reasoning (Nelson & Demir-Lira, 2023). Furthermore, maternal language complexity and diversity of vocabulary is positively associated with improvements in executive function during early childhood (Daneri et al., 2019).

Recent work has also highlighted the importance of cognitive stimulation in language development. In particular, a more stimulating home environment is associated with better receptive language performance as well as expressive language quality and complexity (Lurie et al., 2021). Cognitive stimulation is positively associated with children’s verbal development in the first five years of life (Rodriguez & Tamis-LeMonda, 2011). This begins early in development, with infants whose caregivers initiate more conversations having higher receptive and expressive language skills in toddlerhood (Salo et al., 2022). Children exposed to complex parental language, featuring longer sentences, diverse vocabularies, and exposure to various word types, tend to have larger vocabularies and more advanced syntax (Hoff, 2003a, 2003b; Huttenlocher et al., 2010; Rowe, 2008). Longitudinal analyses also demonstrate the importance of using complex vocabulary as well as speech beyond immediate contexts for early childhood vocabulary development (Rowe, 2012). Additionally, children’s language experience, particularly conversational turns—the back-and-forth between caregiver and child—is especially important for language development from an early age (Donnelly & Kidd, 2021; Ferjan Ramírez et al., 2020). Caregiver labeling of objects in a picture book-sharing task and maternal linguistic diversity and complexity

is associated with child vocabulary and ability to categorize objects during early childhood (Poulin-Dubois et al., 1995) and later receptive and expressive language (Daneri et al., 2019; Vernon-Feagans et al., 2013).

Additionally, cognitive stimulation has also been linked to academic achievement and school readiness. Cognitive stimulation in the home early in life is positively associated with children's academic skills in 5th grade (Tamis-LeMonda et al., 2019). Moreover, several studies have documented the importance of cognitive stimulation during adolescence such that teens with more stimulating home environments have greater academic achievement (Eamon, 2005; Simpkins et al., 2009) and greater improvement in academic skills over time, even after adjusting for earlier levels of academic skills (Hardaway et al., 2020). Recent work found that cognitive stimulation in the home at 54 months was positively associated with academic achievement during adolescence and educational attainment in adulthood (Whitaker et al., 2023), suggesting that cognitive stimulation in the home may play a long-term role in academic outcomes. Importantly, children with high cognitive stimulation across multiple settings including the home, preschool, and first grade classrooms had the highest academic achievement (Crosnoe et al., 2010), which may suggest that high levels of cognitive stimulation across settings supports improved academic and cognitive outcomes. However, it is possible that these findings are a proxy for high resource families living in places or prioritizing enriching childcare and school environments. Collectively, this work demonstrates that cognitive stimulation plays an important role in children's cognitive and language development as well as academic outcomes.

SES, cognitive stimulation, and cognitive function – The role of brain development

The topic of cognitive stimulation is particularly salient in the context of socioeconomic disparities. Foundational work and many replications over decades have shown that on average families with higher income and education provide greater cognitive stimulation, both when looking at global measures of stimulation as well as specific measures such as language exposure (Bradley et al., 2001; Gilkerson et al., 2017; Hart & Risley, 1995; Rosen et al., 2020). Moreover, the association between cognitive stimulation and cognitive development is particularly strong among children raised in low-SES households (Barros et al., 2010). Importantly, these socioeconomic differences are likely due to the time, energy, and resource constraints of low-income parents (e.g., having to work multiple jobs). Supporting this notion, when families experience increases in income over time, this corresponds with an increase in cognitive stimulation in the home (Votruba-Drzal, 2003), suggesting that when given the opportunity and resources, families seek to provide stimulating experiences for their children.

Importantly, cognitive stimulation may play a critical role in the well-documented SES disparities in executive function (Lawson et al., 2018; St. John et al., 2019), language ability, and academic achievement in children (Brito, 2017). Many studies have suggested that socioeconomic disparities in cognitive and academic function are explained at least in part by differences in cognitive stimulation. Further, several studies have found that cognitive stimulation mediates SES-related differences in executive function (Hackman et al., 2015; Rosen et al., 2020; Sarsour et al., 2011), attention (Dilworth-Bart et al.,

2007), receptive and expressive language (Humphreys et al., 2020; Lurie et al., 2021), and academic achievement (Chien & Mistry, 2013; Crosnoe & Cooper, 2010; Larson et al., 2015). Language exposure and experience also play an important mechanistic role in explaining socioeconomic disparities in the development of both language skills (Hoff, 2003b; Huttenlocher et al., 2010) and executive function (Daneri et al., 2019). Therefore, interventions designed to increase cognitive stimulation experienced by infants and young children may reduce socioeconomic disparities in these outcomes.

Importantly, cognitive stimulation is believed to contribute to cognitive and academic outcomes by the influence it may exert on brain development. Indeed, differences in features of brain structure and function, such as cortical thickness and task-based activation have been shown to be relevant for cognitive outcomes. For example, Shaw et al. (2006) showed cognitive ability (operationalized using Weschler intelligence scales) to be related to dynamic changes in cortical thickness during childhood and adolescence such that children with higher scores exhibited a faster rate of change in cortical thickness. Other work has shown verbal memory performance to be associated with the thickness medial temporal regions, and visuomotor speed and set shifting to be associated with thickness of the lateral parietal cortex (Dickerson et al., 2008).

While many studies document how distal environmental factors such as socioeconomic status (SES) and poverty are associated with widespread differences in brain structure and function (Farah, 2017; Finn et al., 2017; Gur et al., 2019; Hackman et al., 2021; Hair et al., 2015; McDermott et al., 2019; Piccolo et al., 2016; Rakesh, Cropley, et al., 2021; Rakesh et al., 2022; Rakesh, Seguin, et al., 2021; Rakesh, Whittle, et al., 2023; Rakesh, Zalesky, et al., 2021; Rakesh & Whittle, 2021; Rosen et al., 2018; Sripada et al., 2022; Whittle et al., 2017). Fewer studies have evaluated the proximal environmental mechanisms, such as cognitive stimulation, that may explain these associations (Lurie et al., 2024; Rakesh, Zalesky, & Whittle, 2023; Rosen, Lurie, Sambrook, Meltzoff, & McLaughlin, 2021; Rosen, Sheridan, Sambrook, Meltzoff, & McLaughlin, 2018). A 20-year longitudinal study on low-income children found that cognitive stimulation at age four years, but not at age eight years, was linked to cortical thickness in the ventral temporal cortex and lateral prefrontal cortex during adolescence (Avants et al., 2015). These findings provide support for the notion that cognitive stimulation may be most impactful on brain development earlier in life. The study did not investigate the association between these brain structure differences and long-term behavioral outcomes, leaving the potential long-term associations with cognitive outcomes uncertain. However, given the role of the temporal and lateral prefrontal regions in higher-order cognitive functioning including language ability and executive function (Friedman & Robbins, 2022; Price, 2010), alterations in the thickness of these regions could serve as pathways linking stimulation to functional outcomes. Indeed, other work has shown that SES-related variation in cortical thickness in frontoparietal regions involved in executive function can be explained by differences in cognitive stimulation (Rosen et al., 2018). Furthermore, recent work found that SES-related differences in recruitment of visual processing regions and regions important for attention allocation during visual attention and working memory may be partially explained by differences in cognitive stimulation (Rosen et al., 2021). Measures of the school environment, which may indirectly measure cognitive stimulation, have also been shown to be associated with functional connectivity (Rakesh,

Zalesky, et al., 2023). Low cognitive stimulation has also been shown to be associated with differences in neural activation in visual and frontoparietal regions during working memory (Lurie et al., 2024).

The early linguistic environment, a key component of cognitive stimulation, has also been linked to brain structure and function. Multiple studies have probed these associations, shedding light on the overarching trends. Primarily, the quality of linguistic interactions has been found to influence the structure and function of fronto-temporal regions. For example, lower linguistic complexity is associated with more diffuse neural recruitment of the prefrontal cortex during an executive function task (Sheridan et al., 2012). Naturalistic recordings of linguistic exchanges have also unveiled a wealth of insights. Children engaged in more frequent conversational turns—back and forth language exchanges between children and adults—exhibit enhanced functional activation, and improved white matter integrity within the fronto-temporal language network. These neural alterations, in turn, correlate with advanced language skills (Romeo et al., 2018; Romeo et al., 2018). Greater exposure to speech from adults is linked to greater surface area in the perisylvian cortical regions (Merz et al., 2020). Such associations are also evident in early childhood. For example, recent work demonstrates that a greater number of conversational turns between infants' vocalizations and adult responses, and amount of adult language a child is exposed to, is correlated with enhanced white matter integrity (Huber et al., 2023) and myelination (Fibla et al., 2023) in crucial neural pathways that support language development. Additionally, the frequency of conversational exchanges, rather than incidental overheard speech, are linked to resting-state functional connectivity of infant brain networks associated with language processing (King et al., 2021). Finally, language exposure has also been shown to influence developmental trajectories. For instance, the complexity of language exposure during the preschool years has been found to impact the trajectory of cortical development from middle childhood through adolescence (Demir-Lira et al., 2021).

Together, these findings suggest that cognitive stimulation and language experience, in particular linguistic interactions with adults, may influence brain structure and function. These studies provide insights into the neural underpinnings of the link between the environment and cognitive and language development in children.

Interventions targeting cognitive stimulation

Cognitive stimulation and language input have been the focus of intervention programs aiming to improve executive function, language, and academic outcomes among youth. We provide a brief overview of some of these programs below. The Abecedarian Project assigned low-income newborn infants to either an enriched daycare program or a control group (Ramey et al., 2000). The intervention group showed higher cognitive function, including IQ and academic achievement throughout development and into early adulthood. Structural MRI scans conducted years later revealed that male participants in the intervention group had larger brain volume in regions related to executive function and language compared to the control group, suggesting long-lasting cognitive and neural impacts of cognitive stimulation interventions into middle adulthood (Farah et al., 2021). A recent *meta*-analysis has shown that interventions to increase cognitive stimulation

in low- and middle- income countries are effective in improving cognitive stimulation including in measures of the home caregiving environment, mother–child interactions, and maternal knowledge of development (Jeong et al., 2018). These interventions are in turn effective in improving cognitive outcomes for children. For example, a large study from rural Pakistan showed that an intervention designed to increase cognitive stimulation in the home environment in the first two years of life led to higher executive function and verbal IQ later in development (Obradović et al., 2016). Further, a *meta*-analysis showed that integrated intervention studies, which combine nutrition and psychosocial stimulation (including cognitive stimulation), significantly improve developmental outcomes compared to usual care and standalone nutrition interventions, particularly for undernourished children (Dulal et al., 2021). For example, an intervention study from Indonesia found that a combined intervention of nutritional supplementation and cognitive stimulation in 3–5-year-old children resulted in significantly higher increases in intelligence quotient and reductions in attentional problems compared to a control group (Schneider et al., 2018).

Studies have also shown that cognitive stimulation programs to be associated with increases in reading comprehension scores (Reina-Reina et al., 2023) as well as cognitive flexibility, planning, metacognition and inhibitory control (Korzeniowski et al., 2017). Although not the direct results of an intervention, findings from Early Head Start, a federally funded intervention program, found that cognitive stimulation in the home, rather than participation in the program, explained variation in children's vocabulary development (Chapin & Altenhofen, 2010).

Interventions have also demonstrated that increases in income may increase cognitive stimulation in the home and, in turn, improve child cognitive outcomes. For example, in the first year of the ongoing Baby's First Years study which provides cash transfers to low-income families, parents who receive the high cash gift allocate more resources (e.g., buying books or toys) and time to enriching activities with their children (e.g., reading to their children) (Gennetian et al., 2022). This suggests that alleviating financial constraints naturally promotes engagement in cognitively stimulating behaviors, potentially benefiting children's cognitive development.

In summary, empirical research consistently underscores the enduring impact of cognitive stimulation on enhancing children's cognitive outcomes and brain development. These findings hold particular relevance in the context of mitigating socioeconomic disparities. They demonstrate the impact of providing cognitive stimulation in various settings, such as the home, day care, and school, to mitigate the negative effects of socioeconomic disparities. However, further research is needed to determine the optimal setting for interventions. Additionally, exploring the interaction and synergy between settings is important, as combining interventions across settings may have cumulative effects and amplify positive outcomes. For instance, research suggests that children benefit more from their child-care experience when their parents provide higher levels of cognitive stimulation at home (Cabrera et al., 2020). This indicates the need to consider the independent and joint effects of different sources of cognitive stimulation in intervention studies. Future research focused in this area will enable policymakers, educators, and researchers to allocate resources and design interventions more effectively, maximizing the potential benefits for children.

Measuring cognitive stimulation

Here, we review common approaches and tools to assess cognitive stimulation both inside and outside the home and make recommendations for choosing measurement tools to guide future research in the field.

Measuring cognitive stimulation in the home with caregivers

Questionnaires, interviews, and observational tools—The Home Observation Measurement of the Environment (HOME) is one of the most well-established measures of different aspects of the home environment (Bradley et al., 1988; Caldwell & Bradley, 2001). It uses both observations as well as structured interviews and/or surveys. The HOME also has a survey version called the HOME-Short Form which contains a cognitive stimulation subscale (Mott, 2004). The HOME assessment typically takes place in the family's home, allowing for observations about the environment (e.g., how many books are visible). The HOME has several versions designed to assess the home environment at different developmental periods including Infant/Toddler, Early Childhood, Middle Childhood, Early Adolescence, and Late Adolescence. Alongside noting observations, the interviewer asks the caregiver a series of questions about their experiences at home with the child and scores their answers on a binary scale (e.g., Does your child have toys designed to teach numbers?). The HOME has several subscales that include questions about cognitive stimulation. Recently, researchers have constructed subscales for cognitive stimulation by either grouping or conducting a factor analysis (Hackman et al., 2015; Rosen et al., 2020, 2021). The HOME measures caregiver involvement in learning, access to developmentally appropriate learning materials, a variety of experiences, and a complex linguistic environment (Mott, 2004). The HOME has been used extensively in the United States, but its relevance and utility cross-culturally has been a matter of investigation. For example, one study in Kenya failed to demonstrate the same factor structure from the original HOME but did find evidence for convergent validity. The study demonstrated the expected associations with both maternal education and developmental outcomes (Holding et al., 2011). An adapted version of the HOME has been used in low and middle-income countries including Tanzania, South Africa, Nepal, India, Pakistan, Peru, Brazil, and Bangladesh (Jones et al., 2017). While this measure does demonstrate a valid and consistent 3 factor structure, the factors do not clearly map on to factors using the HOME in western contexts.

An updated version of the HOME accounts for more contemporary households (Lansford et al., 2022) by incorporating items pertaining to new technology including computers and smartphones in homes, reflecting a more diverse set of family structures than the original version. For example, it accounts for variability in book ownership across cultural contexts to a greater extent. The HOME-21 was tested in two large samples and was found to have strong correlations with expected aspects of the family environment including parental income and education, even when excluding items related to having disposable income (Lansford et al., 2022). In addition to the HOME, the Observational Record of the Caregiving Environment (ORCE; described in more detail in subsequent sections), developed by the National Institute of Child Health and Human Development Early Child

Care Research Network (NICHD Early Child Care Research Network, 1996) can be used to assess the quality of caregiving in any setting where children are cared for, including homes.

The StimQ2 is a questionnaire and interview with three different developmental versions, Infant, Toddler, and Preschool (Cates et al., 2023; Dreyer et al., 1994, 1996). While the HOME assesses stimulation from any adult in the child's home (e.g., parent, a grandparent who lives with the family), the StimQ2 focuses on identifying a primary caregiver in the home and asks specifically about cognitive stimulation from that caregiver. This measure includes reading (e.g. how many books, variety of books, frequency of reading to child), caregiver involvement in developmental advance (e.g. teaching numbers, letters), caregiver verbal responsivity (e.g., back and forth conversations, asking the child describe the world around them), and availability of learning materials (e.g., educational toys and games) subscales, which can either be combined into a total score or used on their own. The interview and questionnaire are available in both English and Spanish and demonstrate strong internal consistency and validity in both languages (Green et al., 2009; Cates et al., 2023; Dreyer et al., 1996; Terwee et al., 2007). The StimQ has also been translated into Italian and found to have strong reliability and validity (De Salve et al., 2023). It has been used in Turkey and found to be correlated with maternal education (Canaloglu et al., 2021). However, to date this measure has not been widely validated across cultures.

The Family Care Indicators (FCIs) questionnaire, developed by the United Nations Children's Fund (UNICEF), aims to assess the home environment of young children in developing countries through large-scale surveys (Frongillo et al., 2003). It focuses on items relevant to cognitive and language development, drawing from sources such as the HOME inventory. The FCI has been shown to be a promising survey-based indicator of the quality of children's home environment (Hamadani et al., 2010). FCIs are designed to be used globally and complement UNICEF's Multiple Indicator Cluster Surveys (MICS), but their inclusion depends on each participating country. Together, they provide a more comprehensive picture of the home environment and its potential impact on child development.

Observation in naturalistic settings and technological tools—In addition to using questionnaires and interviews, various observational coding systems have been developed to assess the quality and quantity of cognitive stimulation in naturalistic settings. For example, picture book reading tasks involve recording videos of interactions between caregivers and children during shared reading sessions (Price et al., 2009; Ribner et al., 2020; Vernon-Feagans et al., 2022). The quality and quantity of cognitive stimulation during these sessions is then assessed by trained staff who code the interactions using standardized frameworks (Brandes-Aitken et al., 2020; Ribner, Tamis-LeMonda, & Liben, 2020; Vernon-Feagans, Carr, Bratsch-Hines, & Willoughby, 2022; Price et al., 2009). Using a book-sharing task allows experimenters to standardize the stimuli presented to the caregiver but still measure how each caregiver interacts with their child and the book. Researchers can use this task to measure language quantity, complexity, conversational turns, linguistic distancing, and joint attention, which have been shown to be associated with children's language skills, math skills, and executive function.

Researchers have also used laboratory-based problem-solving tasks to observe how a caregiver interacts with a child when they must solve a difficult problem. In these tasks, researchers can quantify parental scaffolding (Bernier et al., 2010; Marciszko et al., 2020). The Parent-Child Interactions Rating Scale (PCIRS) and the infant adapted version (PCIRS-IA) can be used during free play and coded for various aspects of parent–child interaction including stimulation of cognitive development. Maternal behaviors rated highly on this subscale include focusing the child's attention on an object or particular features of an object, demonstrating how an object works, responding to the child verbally, engaging in and encouraging joint attention, responding to the child's bids for attention and play, elaborating on a particular activity and staying with an activity for a period of time, verbally describing the child's actions, and using complex language (NICHD Early Child Care Research Network, 1999; Roby et al., 2021). These observational methods are helpful for studying caregiver–child interactions in a naturalistic context. However, they only provide a snapshot in time and may be biased by caregivers being aware that they are observed. Of note, maternal scaffolding styles during book-sharing and storytelling differ across cultures and this should be considered when designing studies and interpreting results (Rochanavibhata & Marian, 2021). However, while there may be variations in parenting styles among groups, the associations between parenting practices and child development tend to apply universally across cultures, with only occasional exceptions (Prevoo & Tamis-LeMonda, 2017).

Technological tools now allow researchers to assess different aspects of cognitive stimulation. Digital Language Processors (DLPs), such as Language Environment Analysis (LENA) recorders, are becoming widely used to assess children's linguistic environment. These small recorders can capture up to 16 hours of audio while being worn by children (e.g., in a vest or shirt pocket). Then software can be used to automatically obtain metrics on the recoded audio files to estimate aspects of the child's language environment, including adult words spoken to the child, conversational turns, child vocalizations, and audio environment (separating meaningful speech from TV and electronic sounds). Raw audio can also be retained for later transcription. Of course ethical considerations must be taken when retaining audio files (see Cychosz et al., 2020 for a discussion). A recent *meta*-analysis showed a moderate association between LENA's automated measures and language outcomes, in agreement with previous LENA validity literature (Wang et al., 2020). LENA has predominantly been utilized in English and Spanish, with published studies validating adult word counts in various languages (*LENA* Foundation, 2024). For example, the use of LENA has been validated for Vietnamese (Ganek & Eriks-Brophy, 2018), Chinese (Gilkerson et al., 2015), and European French (Canault et al., 2016). The LENA foundation states that while word counts in other languages may be less precise, users can still confidently track changes over time and identify periods of extensive verbal interaction, as the error rate is anticipated to remain consistent (*LENA* Foundation, 2024). This has been validated by research that shows that performance is comparable even for children who are dissimilar from the original training set (Cristia et al., 2021).

In addition to language exposure, a recently developed tool measures caregiver–child proximity. While having high proximity does not guarantee high levels of cognitive stimulation (e.g., a parent could be sitting close to their child, but looking at their

phone), enriching caregiver–child interactions are facilitated by close contact (e.g., allowing caregivers to see and respond to child cues, physical touch, and interactions). Further, measuring caregiver proximity in conjunction with other measures of cognitive stimulation could provide important insights into the patterns of caregiver–child interactions associated with cognitive stimulation. A device known as a TotTag, worn by both caregiver and child, was developed to measure caregiver–child proximity (Salo et al., 2022). In this proof-of-concept study, experimenters had children from two families wear both the TotTag and LENA devices simultaneously to assess the association of proximity with linguistic experience (Salo et al., 2022). The study found variation in proximity both within and between dyads, and that increased proximity was correlated with higher levels of language input. In conjunction with naturalistic language recorders and observation, measuring caregiver proximity could provide important information about cognitive stimulation from caregivers.

Measuring cognitive stimulation outside the home environment

As highlighted earlier, cognitive stimulation outside the home, such as in early childcare and school settings may also play a critical role in cognitive development (Crosnoe et al., 2010). Methods to directly measure cognitive stimulation outside the home are not common. While LENA devices can be used in a school or daycare settings (Kelly, 2019), most studies focus on language in the home. This focus is partially due to recording consent laws and the complexity of approval from the ethics board to record outside the home. Measuring cognitive stimulation outside of the parent–child dyad can be more complex as there are multiple factors at play. Combining multiple methods, such as observations, assessments, and surveys, can provide a more comprehensive understanding of the cognitive stimulation received in various contexts. Surveys, such as the National Association of Secondary School Principals Comprehensive Assessment of School Environments, the School Development Program, and the San Diego Effective Schools Student Survey, evaluate social relationships and academics and quantify the perception of school staff's helpfulness, teacher–student relationships, and student–peer relationships (Bradshaw et al., 2014; Zullig et al., 2010). While these measures capture important aspects of the school environment, they do not directly assess cognitive stimulation. However, they provide insights into the overall school environment and factors that can contribute to students' engagement and academic experiences. Some questionnaires, such as the Approaches to Teaching Inventory (Trigwell & Prosser, 2004), measure the extent to which the teacher emphasizes students' active involvement, independent thinking, as well as deep understanding and conceptual development. However, questionnaires that deliberately and specifically enquire about cognitive stimulation in school settings by assessing instructional style and quality, engagement of critical-thinking and problem-solving skills, and participation in extracurricular activities at school are needed.

Observational assessments that specifically evaluate cognitive stimulation outside the home can also be valuable. For example, the Infant/Toddler Environment Rating Scale (ITERS) can be used to evaluate the quality of care in infant and toddler daycare settings for children under age 30 months (Harms et al., 2017). This measure assesses cognitively enriching activities (e.g., those that promote fine motor skills, art, reading books, helping children use

and understand language) as well as teacher involvement. Complementary to the ITERS is the Early Childhood Environment Rating Scale (ECERS), a widely used observational tool designed to assess the quality of early childhood education programs for children up to five years of age (Harms et al., 2014). A recent *meta*-analysis explored the relationship between Environment Rating Scales (ERS) scores and child–caregiver ratios, demonstrating the tool's potential for cross-cultural use (Vermeer et al., 2016). Importantly however, previous research across countries failed to detect the six dimensions indicated in the original structure of ECERS and instead reported a three factor structure (Betancur et al., 2021; Gordon et al., 2013; Mayer & Beckh, 2016) and small effect sizes for regressions predicting child outcomes (Gordon et al., 2013). The Observational Record of the Care Environment (ORCE; NICHD Early Child Care Research Network, 2005), is a qualitative and quantitative measure of the early child caregiving environment across settings and includes ratings of emotional support and guidance offered by caregivers in response to a child's emotional and behavioral needs, positive regard for the child's perspective, organization of space and time, language stimulation, materials and activities, and engagement. This measure has previously been used to assess cognitive stimulation in early childcare education settings (Crosnoe et al., 2010; Whitaker et al., 2023) but has not been widely applied (Manning et al., 2017). Importantly, it centers on the child's experience and has been intentionally crafted for versatile use across diverse childcare environments without modification, and has even been used to assess stimulation in institutions, foster care homes, and non-foster care homes (Nelson et al., 2007). While the ORCE has been used in Romania (Fox et al., 2011), we are not aware of work validating its use across cultural contexts.

For school-aged children, the Classroom Assessment Scoring System (CLASS) can be used to assess the quality of teacher-child interactions in early childhood and elementary school classrooms (Pianta et al., 2008). The CLASS has been validated in other high-income contexts (Westergård et al., 2019); however, the high level of training required to make consistent qualitative judgements using CLASS has limited its use in developing countries (The Classroom Assessment Scoring System (CLASS), 2017). Further, while neither the CLASS nor ITERS/ECERS directly measure cognitive stimulation, they include dimensions that capture cognitive stimulation as an essential aspect of practices that promote critical thinking, problem-solving, and conceptual understanding (Pianta et al., 2008), or include items that capture presence of materials, activities, language interactions, and teacher-child interactions that foster cognitive development (Harms et al., 2014). These measures have previously been shown to be positively correlated with a range of academic and language skills (Mashburn et al., 2008). Further investigation is needed to fully understand the extent of the role of cognitive stimulation in school and caregiving environments (versus for example warm and supportive caregiving or positive teacher-student relationships) on cognitive development, and merit investigation in developmental cognitive neuroscience studies.

Other than home, childcare, and school settings, the neighborhood context also plays an important role in child developmental outcomes (Leventhal & Brooks-Gunn, 2000). To our knowledge, there are no measures that directly assess cognitive stimulation in the neighborhood. Geo-coded objective measures such as Child Opportunity Indices (COI) (Noelke et al., 2024), provide data on neighborhood-level factors that could be linked to

cognitive stimulation, including teacher experience, availability of early child-care centers, and access to green spaces. But these measures only assess the presence of resources that could increase the probability that someone might experience stimulation in their neighborhood context. These measures do not capture whether the child engages with the available resources in a way that provides cognitive stimulation. There is a need for the development of surveys and questionnaires that directly assess individuals' experiences of cognitive stimulation in the neighborhood context. These self-report measures could inquire about the availability, accessibility, and utilization of educational resources, cultural events, and community programs. For example, questions would assess the frequency of library or museum visits, participation in educational or enrichment programs, or perceived opportunities for intellectual engagement.

Selection a measure of cognitive stimulation

When selecting a tool most appropriate for one's research goals, researchers should be mindful that cognitive stimulation is a multidimensional construct and can be assessed both directly and indirectly across modes (i.e., caregiver-mediated and non-caregiver-mediated) and contexts (i.e., inside the home and outside the home). To guide future research, we have created a taxonomy for the measurement of cognitive stimulation in these different ways (Fig. 1). When cognitive stimulation is the focus of a study, researchers should utilize observation-based measures and administer questionnaires that assess cognitive stimulation across different modes (caregiver and non-caregiver mediated) and measurement type (indirect and direct) across different environments. For example, this could entail administering the HOME interview (direct and indirect caregiver mediated), direct observation of caregiver-scaffolding (direct, caregiver mediated), LENA recordings (direct and indirect, caregiver or other adult mediated, depending on recording context), measures of school quality (indirect, non-caregiver mediated), teaching practices (indirect, non-caregiver mediated), and teacher–child interactions (direct, non-caregiver mediated). Measuring cognitive stimulation outside the home and with other adults is critical, but we are limited in our ability to do so due to a lack of measures that *directly* assess cognitive stimulation. We hope this review will prompt the development of better measures to assess cognitive stimulation outside of the home.

If researchers aim to assess cognitive stimulation comprehensively but have limited time or resources for assessment, we suggest combining a measure of caregiver-mediated (e.g. HOME-SF or questionnaire version of StimQ) with a measure of non-caregiver mediated exposure and experience (e.g. school quality). Below we outline several other considerations when choosing the right measurement tool.

In addition, researchers must weigh several factors including participant and researcher burden, environment to be assessed, time scale assessed, and specificity of the measure. Interview and observational measures including the HOME and the StimQ provide in-depth parent-reported measures of cognitive stimulation in the home. This approach has many strengths, including flexibility (i.e., the interviews are structured, and yet allow for follow-up and clarifying questions) and is less subject to a parent or caregiver's own interpretation of the question. Additionally, the observation component of the HOME allows for real time

assessment of aspects of cognitive stimulation such as “the parent responds verbally to the child’s vocalizations” that would be difficult to assess via survey. The original conception of the HOME is that it takes place *in the home*. This alleviates a large portion of the burden on families to travel into the lab and may be less intimidating for families who are not used to being in a university setting. However, this creates a larger burden on researchers to travel to families’ homes. During the COVID-19 pandemic, safety-related closures necessitated improvisation with research teams studying children and families. Some research groups moved their HOME assessments to a video-based remote session, which appears to be an effective method of assessing cognitive stimulation while minimizing the burden on both researchers and families (Rosen et al., *in prep*). Similarly, the StimQ could be conducted via video chat. If cognitive stimulation is a major focus of the study, both the StimQ and HOME are good options conducted as interviews either in the home or virtually.

If cognitive stimulation is not the main focus of the study, both the StimQ and the HOME have been adapted as surveys. This significantly reduces the time it takes to complete these measures and adds a great deal of flexibility. The HOME-SF has been shown to have moderate to high reliability for older children, but not younger children (Mott, 2004). Like the original HOME, the HOME-SF cognitive stimulation subscale demonstrates construct validity in that is correlated with demographics including parental income and education (Mott, 1995). Of note, when conducted as surveys, one loses the option for clarification by a researcher. For example, if confronted with the question “Does your child have a toy that teaches colors?” a caregiver could interpret that to mean an electronic toy that says the colors when the buttons are pressed and may respond in the negative. However, an interviewer could clarify that toys designed to teach colors could include blocks of different colors or any other toy that the caregiver uses to highlight and talk about colors. Researchers must also consider participant age-group. Measures like the HOME and StimQ are normed for particular ages. The HOME has versions that span ages 0 to 15 years while the StimQ spans 0 to preschool age (Bradley et al., 1988, 2000; Dreyer et al., 1994, 1996; Mendelsohn et al., 1999; Totsika & Sylva, 2004). These ask about a wide period of development to assess cognitive stimulation in the home holistically.

Finally, researchers should be mindful that in-depth measures including naturalistic measurements of behavior and language typically only capture small snapshots of time. For example, in-lab observational measures of for example parental scaffolding during a problem-solving task will provide an in-depth assessment of caregiver–child interaction, but only provide a small snapshot in time and focus on specific types of behaviors. Similarly, naturalistic language recordings provide hours of data for language exposure and experience but are limited to only a couple of days of a child’s life. Furthermore, these only capture one aspect of cognitive stimulation (i.e., language).

In sum, where possible, a comprehensive assessment of caregiver mediated and non-caregiver-mediated cognitive stimulation in and outside the home is ideal. However, when that is not possible, researchers should consider participant and researcher burden, the relevance of the context and modes, and the timescale being assessed in the context of their research question to make the appropriate decision for their study. It is also important to note that most of these measures were developed and used primarily in Western countries.

Therefore, researchers must also consider the established validity of the tool within the context of interest. We hope this review will spark the development and validation of measures of cognitive stimulation across diverse cultural contexts.

Open questions and future directions

While our understanding of how cognitive stimulation impacts development has expanded, several questions remain and require further study.

Measuring and assessing cognitive stimulation across development

Much of the literature focuses on cognitive stimulation in early childhood, and even studies that investigate cognitive stimulation in older children and adolescents often focus on retrospective questions about experiences that occurred in early childhood. This is likely based on the understanding that the brain is most plastic and receptive to the positive and negative influences of environmental experiences earlier in development (Greenough et al., 1987; Thomas Boyce & Hertzman, 2018), as well as increased reliance on caregivers for not only survival but as the primary source of social interaction available to facilitate cognitive stimulation. However, enriching experiences are likely to continue to have an influence on development even at later ages. The HOME has an early and late adolescence version which ask questions relevant to cognitive stimulation including access to developmentally appropriate learning materials, caregiver involvement in learning, and attending enriching experiences outside of the home (Bradley et al., 2000). In contrast, the StimQ does not include a version past preschool (Cates et al., 2023; Mendelsohn et al., 1999).

Very few studies have investigated how cognitive stimulation relates to developmental outcomes in adolescents. However, a recent study found that cognitive stimulation in early adolescence predicts increases in academic outcomes two years later among low-income African American teens (Hardaway et al., 2020). The limited research in this area raises many issues about our understanding of how cognitive stimulation impacts cognitive and neural outcomes across development. First, it is unclear what exactly constitutes cognitive stimulation during adolescence. Some measures of cognitive stimulation from early development (e.g., parent is involved in learning numbers) become much less relevant as a child masters that information. Once a child enters school, the primary setting for learning may shift from the home to the school. In fact, the HOME measure for early adolescence doesn't include questions about parental involvement in schoolwork or learning at home, but rather focuses on enriching activities (e.g., music lessons, attending a performance) (Bradley et al., 2000; Lansford et al., 2022). However, it is unclear to what extent parental involvement in learning at this age is relevant for academic outcomes. It is possible that there is a sensitive period in which cognitive stimulation is most impactful, especially when the groundwork for neural development is being laid (Gabard-Durnam & McLaughlin, 2020). However, it remains unknown whether stimulation can have an impact later in development, particularly during adolescence, a period in which individuals may have a renewed sensitivity to their caregiving environment (Colich et al., 2021). Future longitudinal research is needed to assess the impact of stimulation across development.

Shifting from a parent-centric to a child-centric lens.—Transitioning from a parent-centric perspective to a child-centric lens is essential when measuring cognitive stimulation. While parent–child interactions are crucial, understanding cognitive stimulation necessitates considering various contexts, such as early childcare settings, schools, and neighborhoods. Adopting a child-centric approach would require broadening the scope of measurement and allowing for a comprehensive assessment of the diverse influences on a child's cognitive stimulation beyond a specific parent–child relationship to understand the environmental factors, instructional practices, and community resources that influence a child's cognitive stimulation and development. This will require studies to focus on a more holistic view of a child's experience, including parent interviews along with classroom or childcare assessments and assessments of broader community and the child's use of those resources.

Exposure versus experience and engagement.—Exposure refers to the availability or presentation of stimulating materials, such as toys, books, or educational apps. While exposure can pique a child's initial curiosity, its impact on cognitive development may be limited without active participation. A child surrounded by educational toys might not engage with them, potentially due to developmental stage, lack of interest in the specific materials, or absence of adult guidance. Experience, on the other hand, is characterized by active engagement with the stimulating environment. For example, this may include building with blocks, solving puzzles, following along with interactive stories, and asking questions. Crucially, such experiences can often involve adult interaction, which fosters deeper understanding and facilitates the application of newly acquired skills. Several measures reviewed here consider the presence or availability rather than engagement with cognitive stimulation. For example, the StimQ2 has a subscale that assesses availability of learning materials. Similarly, neighborhood measures often capture the presence of resources that could potentially stimulate cognitive development (e.g., teacher experience). Alongside availability, it is important to capture whether children are actively engaging with the available resources in a manner that provides meaningful cognitive stimulation. While a child could have access to learning materials (e.g. books, toys with numbers and letters on them), in the absence of a caregiver that may scaffold how to meaningfully engage with those materials, some children may struggle to learn from them. On the other hand, it is possible that caregivers who cannot afford specific toys or games designed for learning may be able to create such things in their environment. For example, one study found meaningful improvements in cognitive development among children of low-income mothers in Pakistan who received an intervention that taught them to create learning toys out of everyday objects (Obradović et al., 2016; Yousafzai et al., 2015). Studying the difference between exposure to stimulating materials and active engagement with them is crucial for understanding the effectiveness of early childhood interventions and educational programs.

Changing landscape of technology.—In today's digital age, technology is pervasive and deeply integrated into children's lives. Education, socialization, and recreation have undergone significant transformations, with digital platforms becoming primary means of engagement. This shift necessitates a deeper understanding and measurement of cognitive stimulation in the context of this digital landscape. Children now have access to diverse digital experiences that shape their cognitive development. Social media platforms enable

new modes of socialization, while video games and online platforms provide unique avenues for recreation and learning. These digital environments differ from traditional ideas of cognitive stimulation, which tend to involve a caregiver or another adult. However, many digital learning games are interactive and responsive and therefore may provide children with important learning opportunities. In this evolving landscape, it is crucial to consider these digital environments and their potential impact on cognitive processes such as critical thinking, problem-solving, and creativity. Therefore, traditional methods of measurement may need to be adapted to capture the impact of digital platforms, interactive media, and online learning environments on cognitive development.

While studies have shown that screen time during infancy may hamper optimal development of executive function (Law et al., 2023), and systematic reviews have shown the negative association between screen time and attention in children (Santos et al., 2022), others argue that the evidence linking digital engagement and negative outcomes is frequently overstated, focused on extreme users, and supported by studies lacking requisite nuance and complexity to discern specific effects (Haddock et al., 2022). In fact, a recent *meta*-analysis found that there was no overall association between screen media use and vocabulary, but a small positive association between exposure to educational material via screens and vocabulary (Jing et al., 2023). Importantly, the distinction between active and passive screen time is also critical (Radesky et al., 2015). Findings from a study of Chinese preschool children showed that passively engaging with screens had a negative impact on their mathematics achievement, science performance, executive functioning, and social skills. On the other hand, actively interacting with screens was found to have a positive association with their receptive language skills and science knowledge (Hu et al., 2020).

Furthermore, the way adults use interactive media and interact with children during media use can either enhance or hinder the learning and developmental opportunities provided by such media (Radesky et al., 2015). For example, Mendelsohn and colleagues found that there were differences in the associations between parent–child verbal interactions during media exposure and language development, depending on the content of exposure. Specifically, these kinds of interactions were positively associated with total language development in children exposed to educational but not other types of media (Mendelsohn et al., 2010). Finally, technology use can be useful for cognitive stimulation and learning in low-income contexts. For example, an 8-week tablet-based mathematics intervention program in Malawi showed that 78% of low achieving children showed improved mathematics skills (Pitchford, 2014). These findings highlight the importance of digital technology in supporting learning during childhood. As digital advancements continue to shape our lives, it is crucial to recognize the role of technology in providing cognitive stimulation opportunities for children.

Conclusion

Cognitive stimulation is an important aspect of the early environment and provides children with opportunities to learn, develop, and refine critical cognitive skills. Here, we provide a review of the literature highlighting the important role cognitive stimulation plays in the development of verbal abilities and executive function as well as the brain regions

and networks that support these functions. Research in this area not only sheds light on the critical role of cognitive stimulation in development but also underscores its potential as an effective intervention target for mitigating socioeconomic disparities in children's cognitive and academic outcomes. Further, we review several measures that researchers can use to measure cognitive stimulation both in the home environment and outside of the home including observational methods, interviews and surveys, and technological tools. We hope this work will inspire researchers to continue to conduct research to understand the developmental windows in which cognitive stimulation is most impactful, take more of a child-centered approach and more deeply assess cognitive stimulation from sources outside of the home, and examine the changing role of technology in these important learning opportunities.

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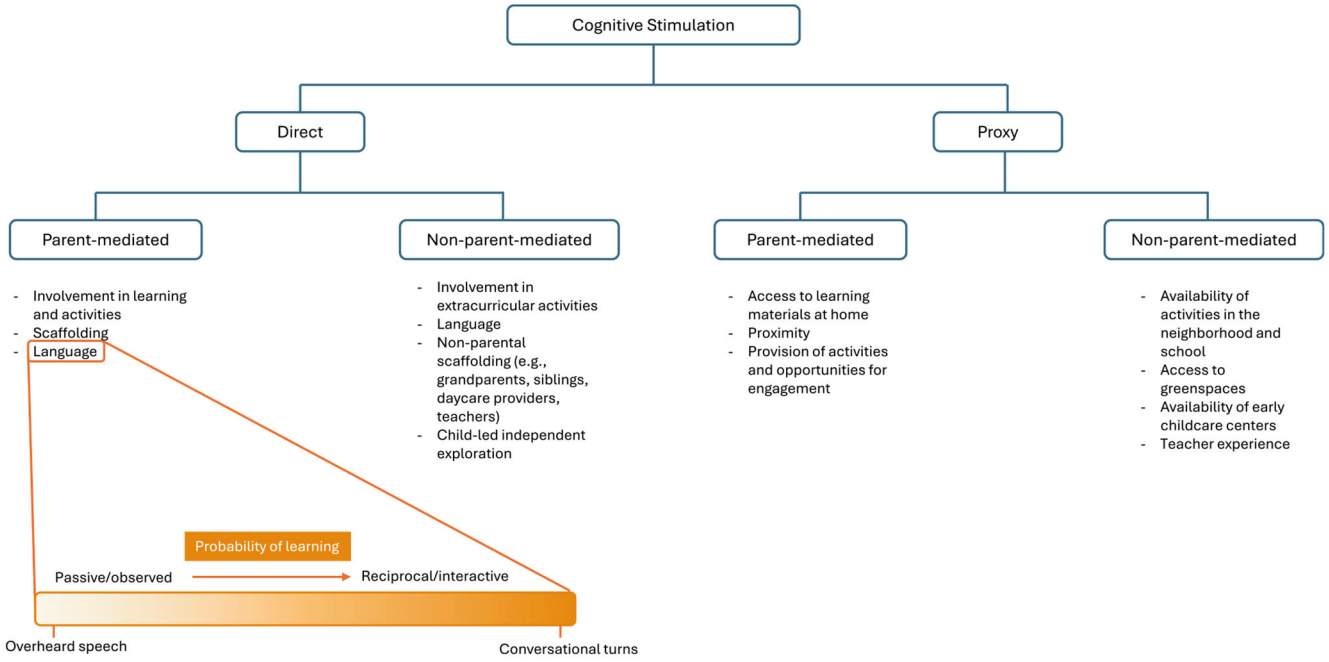

Fig. 1.

A taxonomy for the measurement of cognitive stimulation. Cognitive stimulation can be measured directly or indirectly across different modes. We provide examples of sources of cognitive stimulation under each mode. Using language as an example, we also highlight that stimulation lies along a spectrum and the probability of learning increases as the source of stimulation goes from observed/passive to reciprocal/interactive.