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The biological side of social determinants: Neural costs of childhood poverty

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Abstract Interdisciplinary efforts to foster the development and education of children living in poverty require a comprehensive concept of multiple dimensions, within a systemic approach involving ecological and transactional perspectives. Constructing a common interdisciplinary language dealing with child development in ecological terms is a necessary first step toward building networks that can guide us in designing and implementing comprehensive, coherent actions. In this context, studies of how social determinants influence brain development include critical and sensitive growth periods for different neural systems, modulation of brain development by epigenetics mechanisms, influences of environmental toxins, lack of adequate nutrition, and stress and self-regulatory mechanisms. This neuroscientific agenda pioneers these explorations concerning the elemental components that bear on different levels of organization. Ecological considerations about how poverty shapes child neurocognitive development and its biological and social determinants should identify different protective and risk factors—as well as mediation mechanisms—that could help us better understand poverty's effects and should guide us in designing actions to optimize children's emotional, cognitive, and learning development.

Keywords Social determinants · Childhood poverty · Brain development · Cognitive development · Mediation mechanisms · Sustainable Development Goals (SDGs)

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How biological and social determinants shape human development

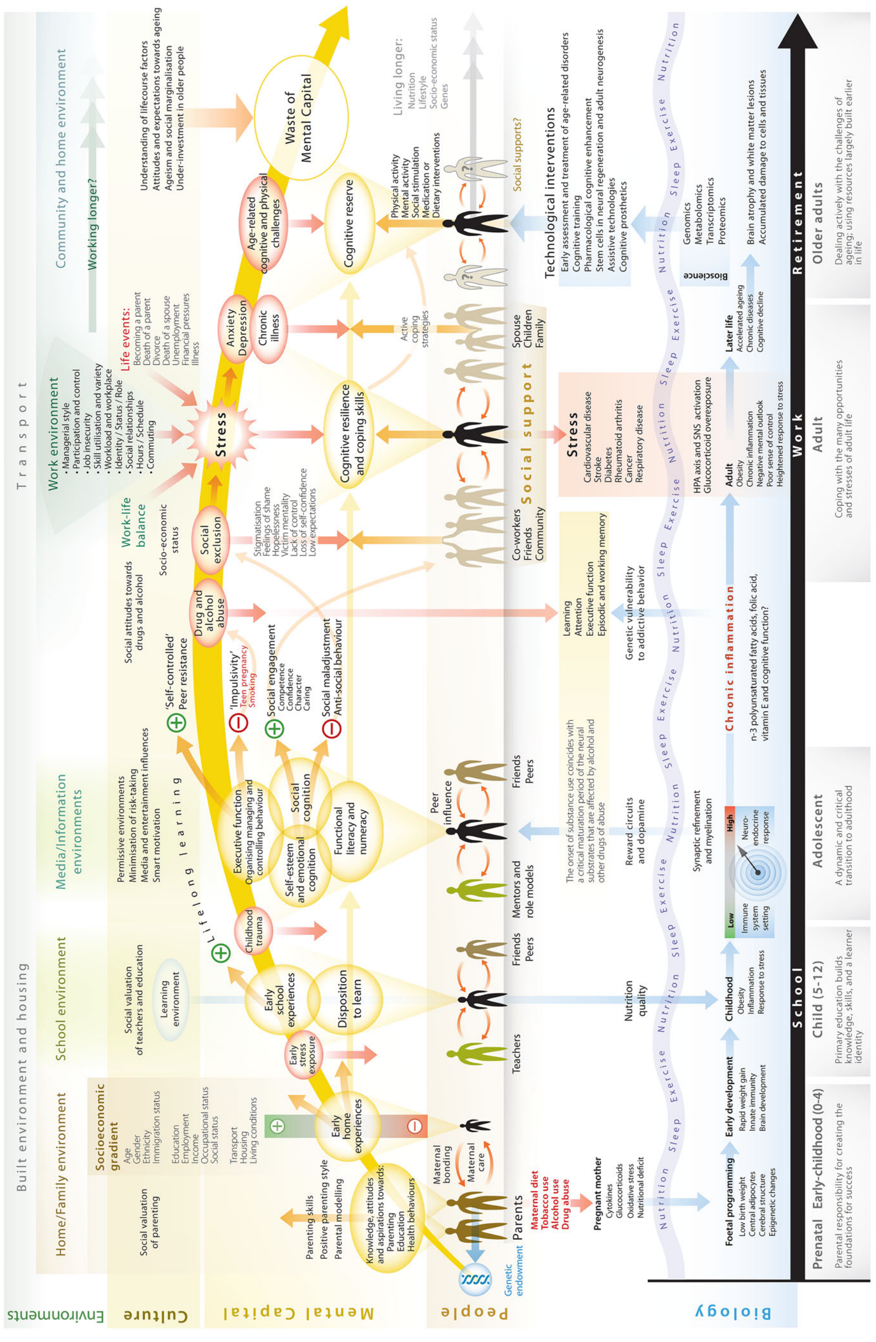
The contemporary consensus about human development postulates that it is a process of continuous integration of interdependent events occurring at different levels of organization (i.e., biological, psychological, and cultural). This way of thinking considers each individual as a complex system made up of different elements that interact at genetic, neural, behavioural, and social levels, creating specific patterns of functioning and evolution in particular historical contexts. During the twentieth century, developmental psychology generated different ecological theories that have contributed to exploratory and experimental frameworks for the study of human development. An example of such approaches is the theory proposed by Urie Bronfenbrenner (1979). In this framework, human development consists of a series of interdependent contexts of development; each of one has a specific pattern of material and symbolic exchanges among institutions and individuals. From the child's perspective, the first context is that in which significant adults and institutions interact directly with her or him during everyday life activities (e.g., family, teachers, peers, schools, churches, NGOs, and neighborhood organizations). In turn, this developmental context is contained within another one in which people and institutions that deal with childcare interact, but without direct interaction with the child (e.g., parent-teacher meetings, which potentially influence parenting and educational practices). A third context, which contains the previous two, is that in which the social, cultural, and economic activities of each community take place (e.g., governmental agencies, trade unions, civic associations, businesses, industry, and media). Likewise, the cultural system of rules, beliefs, and values of each community contains all the previous developmental contexts as well as all the explicit and implicit conceptions of childhood, social equity, and sensitivity to the needs of human development. And each cultural system is contained in a biome, with its flora, fauna, and climate, which in turn are affected by human activity. Finally, all these developmental contexts interact in many different ways over the specific historical time of each community.

Another important ecological approach toward human development, pertinent for the study of teaching and learning processes, is Roger Barker's (1968) behaviour-setting theory. This theory postulates that specific units of analysis combine physical and social elements of the environment that influence human behaviour; as, for example, the class of a specific teacher in a particular school. A behaviour setting's properties are defined by the specific set of its participants' time, place, and behaviour patterns. This means that a behaviour setting exists independently of anyone's direct perception of it; and that it influences the behaviour of those who participate in it, regardless of their individual differences (that is, it modulates participation but does not replace people's roles). In addition, all the setting components are interconnected and self-regulated through different mechanisms—such as intervention programs or actions that specify how to meet the goals, or the correction or elimination of setting elements while the activities are performed (Scott 2005). Both ecological theories are important for understanding the complexity of the processes and mechanisms through which biological and social determinants shape cognitive and learning abilities throughout life. In particular, Bronfenbrenner's (1979) theory has been very productive in the design of policies aimed at improving the development of poor children, as in the case of the Head Start program in the United States. Both theories continue to have great potential in guiding these types of efforts everywhere.

In 2008, the UK Government Office for Science published a report of the Foresight Project on mental capital and wellbeing that provides an independent assessment; it is intended to inform policymakers and the public about the implications of future challenges to mental development throughout the life cycle (Beddington et al. 2008). This report took two years to complete and involved over 450 experts and stakeholders from many disciplines and countries, and 80 peer-reviewed papers summarizing the latest evidence (Figure 1). Among the key findings of this effort, which bases its conceptual approach on an ecological consideration of human development, the report highlights the importance of cognitive neuroscience efforts in uncovering neural processes that can help to address social risk factors and to reveal and remediate learning difficulties as early as infancy.

In particular, the scientific study of the influences of poverty on cognitive development is an area with more than nine decades of history, mostly approached by education and developmental psychology (Yoshikawa, Aber, and Beardslee 2012). Until the 1980s, most studies focused on the developmental impacts of poverty's material and symbolic deprivations (Brooks-Gunn and Duncan 1997). Accumulating evidence indicates that, during the first decade and a half of life, low socioeconomic status (SES) and poverty are associated with declining scores on motor, emotional, cognitive, and language development, and with a higher incidence of learning disorders and a decrease in completed years of schooling (Bradley and Corwyn 2002). Regarding the progression of these findings at later stages of development, some studies show a reduced negative impact of poverty on IQ in adolescents (Bradley and Corwyn 2002; Brooks-Gunn and Duncan 1997; Odgers 2015). However, the same trend is not verified when analyzing other measures of mental functioning, such as performance in math and reading skills (Eamon Keegan 2002), or attentional processing (D'Angiulli et al. 2012). Still, less is known about how the inequality gaps between poor and non-poor children may influence their development—an important area of study that is just emerging through the analysis of the predictive value of subjective social status influences on development (Odgers 2015).

Research findings are clear about the potential negative influences of poverty on cognitive development; however, they do not necessarily explain the mechanisms through which poverty generates its influences. The identification of such mechanisms of mediation is not easy because poverty is a complex phenomenon that involves many conditions that could influence cognitive development (Duncan and Magnuson 2012; Lipina 2016). This set of potential mediators shapes a virtual ecology of protective and risk factors of cognitive development, involving multiple individual and environmental factors in all developmental contexts and at different levels of organization. Among such factors, the contemporary literature on development psychology of poverty postulates the following as the most important: prenatal maternal health (nutrition, exposure to environmental toxic agents and drugs, environmental stressors); perinatal health (prematurity, birth weight); quality of early attachment; environmental stressors at home and schools; parenting and care quality and styles; early cognitive and learning stimulation at home, care centers, and schools; parents' and teachers' mental health; developmental disorders; family financial stress; access to social security and health systems; community resources; lack of social mobility; social, political, and financial crises; family, social, and cultural expectations about child development (e.g., discrimination, stigmatization, exclusion); and natural disasters (Bornstein et al. 2015; Brooks-Gunn and Duncan 1997; Bradley and Corwyn 2002; Dornan and Woodhead 2015; Hirsh-Pasek et al. 2015; Moffitt et al. 2011; Yoshikawa, Aber, and Beardslee 2012) (Figure 2).


Environments
Culture
Mental Capital
People
Biology
Built environment and housing
Transport
Home/Family environment
School environment
Media/Information environments
Work environment
Community and home environment
Working longer?
Socioeconomic gradient
Social valuation of parenting
Social valuation of teachers and education
Learning environment
Permissive environments
Minimisation of risk-taking
Media and entertainment influences
Smart motivation
Social attitudes towards drugs and alcohol
Socio-economic status
Work-life balance
Life events:
Understanding of lifecourse factors
Attitudes and expectations towards ageing
Ageism and social marginalisation
Under-investment in older people
Lifelong learning
Knowledge, attitudes and aspirations towards:
Parenting
Education
Health behaviours
Early home experiences
Early stress exposure
Early school experiences
Disposition to learn
Childhood trauma
Executive function
Organising managing and controlling behaviour
Self-esteem and emotional cognition
Social cognition
Functional literacy and numeracy
'Self-controlled'
Peer resistance
'Impulsivity'
Teen pregnancy
Smoking
Social engagement
Social maladjustment
Anti-social behaviour
Drug and alcohol abuse
Social exclusion
Stress
Anxiety Depression
Chronic illness
Age-related cognitive and physical challenges
Cognitive resilience and coping skills
Cognitive reserve
Waste of Mental Capital
Active coping strategies
Living longer:
Social supports?
Genetic endowment
Parents
Maternal bonding
Maternal care
Teachers
Friends Peers
Mentors and role models
Peer influence
Co-workers Friends Community
Social support
Spouse Children Family
Maternal diet
Tobacco use
Alcohol use
Drug abuse
Pregnant mother
Nutrition quality
Reward circuits and dopamine
Synaptic refinement and myelination
Genetic vulnerability to addictive behavior
HPA axis and SNS activation
Glucocorticoid overexposure
Chronic inflammation
Technological interventions
Bioscience
Nutrition Sleep Exercise
Foetal programming
Early development
Childhood
Adult
Later life
School
Work
Retirement
Prenatal
Early-childhood (0-4)
Child (5-12)
Adolescent
Adult
Older adults
Acquisition
Maintenance
Decline

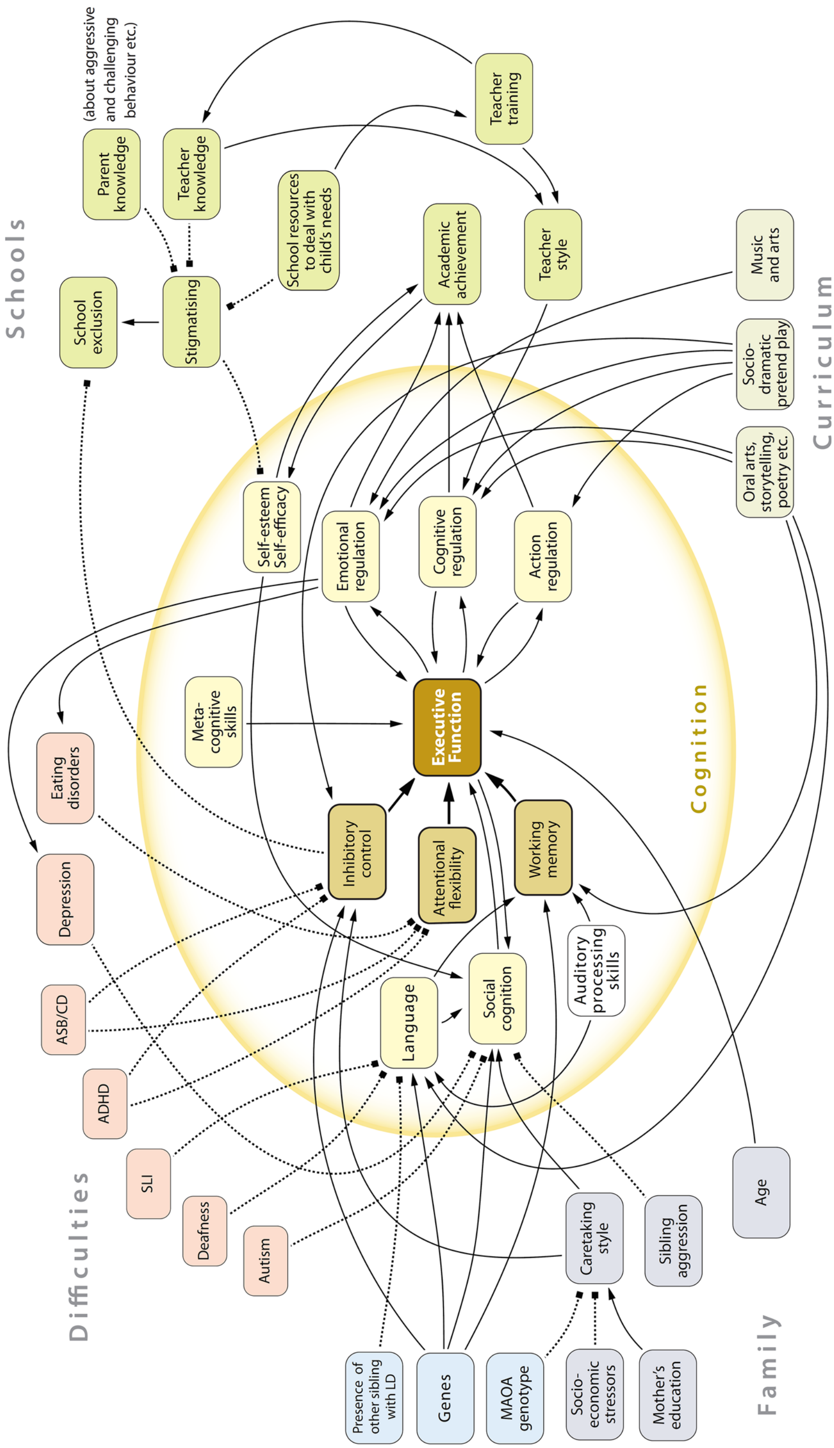
◀**Figure 1** Trajectory of mental capital through life, detailing some of the many factors that influence mental capital and how they are connected across the lifecourse
Note: "Mental capital" refers to the totality of an individual's cognitive and emotional resources, including their cognitive capability, flexibility and efficiency of learning, emotional intelligence (e.g., empathy and social cognition), and resilience in the face of stress. The extent of an individual's resources reflects his/her basic endowment (genes and early biological programming), and their experiences and education, which take place throughout the lifecourse.
Source: Figure and captions are reproduced by permission from Foresight Mental Capital and Wellbeing Project (2008).

Cognitive development's ecology of protective and risk factors is so complex that it is difficult to determine the specific contribution of each factor. The contemporary evidence suggests that the impact of poverty on cognitive development is a function of the accumulation of risk factors, the co-occurrence of adverse experiences, the individual susceptibility of every child to these factors, and the duration of the exposure to such material and/or symbolic deprivation (McLaughlin and Sheridan 2016; NICHD 2005; Wagmiller 2015). For this reason, identifying specific mechanisms remains a central aspect of this field's research agenda. In this context of study, neuroscience is a complementary alternative of value both to deepen our understanding of the impacts of poverty at different levels of analysis, and to contribute to the identification of mechanisms of mediation—both of which eventually could help shape the design of interventions and policies (Blair and Raver 2012).

The humble contributions of neuroscience to the study of childhood poverty

Evidence of brain structural and functional changes due to environmental deprivations

The neuroscientific study of childhood poverty is an area of recent development (Blair and Raver 2012; Gianaros and Hackman 2013; Hackman and Farah 2009; Hackman, Farah, and Meany 2010; Lipina and Colombo 2009; Raizada and Kishiyama 2010; Ursache and Noble 2016). Since the mid-nineties, different researchers have begun to apply neurocognitive behavioural paradigms to compare the performance of children with disparate SES. Then, technological advances in neuroimaging and behavioural genetics allowed the incorporation of neural network, epigenetic, and stress-regulation analysis. The main questions currently included in this neuroscientific agenda focus on some topics already analyzed in the fields of developmental psychology, cognitive psychology, and health sciences, especially regarding the effects and mechanisms of mediation at the behavioural level of analysis. Nonetheless, the intrinsically innovative aspect of the neuroscientific agenda is that neuroscience opened the door to considering elemental components at different levels of organization (i.e., molecular, neural networks, cognition, and behaviour). The following sections focus on the influence of poverty on brain structure and function, and the consideration of different mediators involving epigenetics, stress-regulation, and language-environment mechanisms associated with the experience of childhood poverty. The influences of pre- and postnatal exposure to undernutrition, malnutrition, drugs, and environmental toxic agents are important issues involved in the phenomenon of childhood poverty that we will not approach here, since several reviews recently updated these studies (e.g., Donald et al. 2015; Georgieff, Brunette, and Tran 2015; Grandjean and Landrigan 2014; Thompson, Levitt, and Stanwood 2009; Wiebe et al. 2015).



Schools
Difficulties
Cognition
Curriculum
Family
School exclusion
Stigmatising
Parent knowledge
Teacher knowledge
(about aggressive and challenging behaviour etc.)
School resources to deal with child's needs
Teacher training
Teacher style
Academic achievement
Music and arts
Socio-dramatic pretend play
Oral arts, storytelling, poetry etc.
Self-esteem Self-efficacy
Emotional regulation
Cognitive regulation
Action regulation
Meta-cognitive skills
Executive Function
Inhibitory control
Attentional flexibility
Working memory
Auditory processing skills
Language
Social cognition
Eating disorders
Depression
ASB/CD
ADHD
SLI
Deafness
Autism
Presence of other sibling with LD
Genes
MAOA genotype
Socio-economic stressors
Mother's education
Caretaking style
Sibling aggression
Age

◀**Figure 2** A diagram showing the proposed causal factors involved in the development of executive function
Source: Figure and captions are reproduced by permission from Foresight Mental Capital and Wellbeing Project (2008).

Viewing cognition as consisting of component codes, computed in different ways and programmed to perform complex tasks, leads to new ways of thinking about how the brain might organize thought and emotional processes (Posner and Raichle 1994). Specifically, basic processes involved in early cognitive control and language development, such as the different subsystems of attention, working memory, and cognitive flexibility, are the cornerstone of all forms of cognitive activity and social behaviour throughout the lifespan in most cultural systems worldwide (Sperber and Hirschfeld 2004). Recently, neuroscientific studies have begun to assess associations between different forms of poverty and its impact on basic cognitive processing. Several studies have verified the modulation of socioeconomic characteristics on different attentional, inhibitory control, working memory, flexibility, planning, phonological awareness, self-regulatory, decision-making, and theory-of-mind processes related to different prefrontal and temporal neural systems in infants, preschoolers, and school- and middle school–age children (for recent reviews on this, see Johnson, Riis, and Noble 2016; Lipina 2014; Pavlakis, Noble, Pavlakis, Ali, and Frank 2015; Ursache and Noble 2016).

In some of these studies, researchers have reported that the modulation of SES on performance is neither similar in all the administered measures, nor uniform at all ages (e.g., Farah et al. 2006; Lipina et al. 2013; Noble, Norman, and Farah 2005). Both aspects are worth considering for different reasons. Conceptually, this implies that poverty does not necessarily generate homogeneous and continuous changes in neurocognitive processing. This is consistent with the brain's temporal and regional differences in cortical organization throughout childhood and adolescence (e.g., BDCG 2012). However, although the evidence indicates that SES disparities can adversely affect such different cognitive processes as language, attention, memory, and learning, these findings are not consistent with the notion of low-SES performance as a deficit (D'Angiulli, Lipina, and Olesinska 2012).

This evidence is behavioural in nature; thus, researchers can make only indirect inferences about brain function. In addition, many of these tests are multifactorial—performance could vary for reasons other than those resulting from a specific alteration. Moreover, researchers have found low correlations among these tests, which means that two tasks can engage the same system in different ways. Therefore, we need a thorough examination of poverty's impact on the relationship between cognitive processes and brain function. Magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), and electroencephalography (EEG) neuroimaging techniques—for analysis at the neural level—contribute to improve the understanding of these relationships. A summary of the MRI evidence indicates that: (a) parental nurturance is associated to volumetric changes in the hippocampus—a structure related to memory and learning processes—between ages 4 and 8; (b) family income and mother's education are related to volumetric changes in hippocampus and amygdala—involved in emotional processing—between ages 4 and 22; (c) parental education is related to changes in cortical thickness and volume in different cortical areas (i.e., prefrontal, parietal, occipital)—between ages 4 and 18; and (d) income and parental education are also related to changes in brain growth and volumetric changes in frontal and parietal areas in children from 1 month to 4 years (Avants et al. 2015; Betancourt et al. 2015; Hair, Hanson, Wolfe, and Pollak 2015; Mackey et al. 2015; Noble et al. 2015; Pavlakis et al. 2015; Piccolo, Merz, He, Sowel, Noble, and Pediatric Imaging, Neurocognition, Genetics Study 2016). This evidence also indicates that some of the changes in cortical thickness and volume of areas involved in cognitive control, language, and learning processing correlate with an income, cognitive, and academic achievement gap (e.g., Hair et al. 2015; Mackey et al. 2015; Noble et al. 2015). In turn, evidence from fMRI studies shows: (a) SES variability in the activation of the left occipito-temporal cortex during discrimination of rhymes and combination of sounds during word tasks, in children between ages 4 and 8; (b) SES variability in the activation of the prefrontal cortex during associative learning tasks, in 4-to-8-year-old children; and (c) greater amygdala reactivity to threatening faces in orphans and adults who lived in low-SES homes as children (Pavlakis et al. 2015; Sheridan, Sarsour, Jutte, D'Esposito, and Boyce 2012). Finally, EEG evidence showed (a) SES modulation of topographic maps of resting state, in infants aged 6 to 9 months; (b) SES modulation of control of irrelevant information in tasks demanding inhibitory control and auditive attention processing, in children and adolescents from 3 to 14 years old (Pavlakis et al. 2015).

Mechanisms of mediation: The potentiality of the neuroscientific contributions

Conceptually, current neuroscientific theoretical approaches suggest that neural development often depends on neural activity, which in turn is mediated by experience. It is, therefore, assumed that cognitive and emotional processing and learning shape the neural networks responsible for this processing. In turn, this activity would change the nature of neural representations and their processing, which leads to new experiences and further changes in neural systems. This approach suggests that the basis of cognitive, emotional, and learning development may be characterized by mutually induced changes between neural, cognitive, emotional, and learning levels, in a complex ecological context involving social interactions with cultural specificities (Sirois et al. 2008). In turn, different types of experiences could generate a cascade of heterogeneous consequences at each of these levels. For instance, important differences exist between the impact of lack of expected resources (i.e., deprivation) and the presence of a threat to physical integrity (i.e., threat) (Sheridan and McLoughlin 2014). And the experiences of deprivation and threat could vary among different SES factors in terms of their influences on cognition (Duncan and Magnuson 2012; Lipina 2016; Lipina, Simonds, and Segretin 2011).

The contemporary neuroscientific studies on childhood poverty hypothesize that the two important pathways that affect neurocognitive development are quantity and quality language exposure and the experience of stress, which can operate independently or interactively (Brito and Noble 2014; Demir and Küntay 2014; Ursache and Noble 2016). In such a context of complexity, critical and sensitive periods characterize the structural and functional organization of those brain networks most affected by poverty. These periods refer not only to a time when the human brain is especially sensitive to particular types of external stimuli but also to the time during which the brain is particularly receptive to experiences that contribute to its organization. At a neurocognitive level of analysis, studies show the expression of multiple sensitive periods in sensory systems, several aspects of speech development, and face recognition (Bavelier et al. 2010; Peretz and Zatorre 2005). Plasticity of those neural networks related to language, cognitive, emotional, and learning processes depend on the type of information provided by their own activity. Hypothetically, these processes are run by a diversity of molecular mechanisms in different brain areas, the inhibitory and excitatory balance of different neurotransmission systems, the functional competition between different inputs of information, and the influence of motivation and cognitive control (Bavelier et al. 2010). Thus, the mechanisms responsible for the development of neurocognitive and learning skills are highly complex and interdependent; therefore, theories about the impact of childhood poverty on development and learning cannot be grounded in unilineal relationships involving only a few factors.

Available and replicated evidence from the last three decades indicates that poverty is related to home cognitive and linguistic stimulation. Disparate SES can predict the number of words a child is exposed to and the complexity of his or her language exposure. In such a sense, different aspects of early language development could be mediated by the length of maternal utterances, maternal verbal responsiveness and provision of verbal information, parental use of gestures, and the presence of materials to stimulate learning and literacy at home (Hart and Risley 1995; Hirsh-Pasek et al. 2015; Hoff 2006; Perkins, Finegood, and Swain 2013). Regarding cognitive control, there is evidence about the mediating role of home environment and maternal sensitivity in the association between SES and executive function (Hackman, Gallop, Evans, and Farah 2015). This evidence is mostly behavioural and more research is necessary to explore the neurobiological mechanisms by which parental language influences the brain networks involved in language development (Demir and Küntay 2014; Ursache and Noble 2016). Elucidating these type of mechanisms could help identify which poverty experiences influence which neural networks—information that may improve interventions for optimizing language development of impoverished families.

Since the mid-twentieth century, many studies have found that the regulation of stress response in both children and adults is one of the most important mediating mechanisms of the effect of poverty on emotional, cognitive, and social functioning (Blair and Raver 2016; Fernald and Gunnar 2009; Lupien, McEwen, Gunnar, and Heim 2009). Threats, negative life events, exposure to environmental hazards, family and community violence, changes such as family break-up and moves, job loss or instability, and economic deprivation are more likely to occur in poverty conditions (Bradley and Corwyn 2002; Evans, Dongping, and Whipple 2013; Maholmes and King 2012; Sheridan and McLaughlin 2014; Yoshikawa, Aber, and Beardslee 2012). Neural systems that control complex stress regulation include the hippocampus, amygdala, and different areas of the prefrontal cortex (i.e., HPA axis). Together, these systems—communicating with the immune and cardiovascular systems—regulate the physiological and behavioural responses to stress, adapting to short- or long-term impacts caused by difficulties in adapting, as in chronic situations of abuse or extreme poverty (Karatoreos and McEwen 2013; McLaughlin and Sheridan 2016; Shonkoff et al. 2012). These systems help in the short term to protect against the effects of stress; however, they may be associated with physiological mismatches under conditions of chronic stress, affecting recovery and overall health (McEwen and Gianaros 2010).

Stress and uncertainty caused by economic deprivation increase the likelihood of negative emotional states, anxiety, depression, and anger. In turn, this may trigger more frequent negative parental control strategies, more emotional neglect, and more difficulties in promoting appropriate socio-emotional adjustment in children (Shonkoff et al. 2012). However, some studies show that, even in conditions of poverty, maintaining proper child rearing can be a protective factor of development (e.g., Brody, Dorsey, Forehand, and Armistead 2002), highlighting the environmental plasticity of these regulatory systems. Specifically, analyses of stress-mediating stress mechanisms have generated guiding principles that can help us understand childhood poverty. For instance, Ganzel and colleagues (2010) have suggested that the stressor properties (i.e., magnitude, duration, and chronicity) and type (e.g., social exclusion versus physical threat) modulate the impact on neural networks involved in acute and chronic responses to stress. In this regard, investigators should explore the timing and specificity of neural development that is sensitive to stress processes related specifically to childhood poverty (Lupien et al. 2009; McLaughlin and Sheridan 2016).

Contemporary evidence suggests that higher levels of stress can alter cognitive control processes. For example, evidence indicates that negative parenting behaviours are related to higher basal cortisol levels and lower executive functioning in children (Blair et al. 2011). Some studies have found, at a neurobiological level, that chronic stress mediates the association between lower family income in childhood and reduced prefrontal cortex activation in adulthood during a task of emotion regulation (Kim et al. 2013). In addition, some studies have found that high levels of stress tend to inhibit cognitive control and memory processing and alter learning (e.g., Blair et al. 2010). Thus, it is possible that high levels of environmental unpredictability, uncertainty, and threat may activate neural networks involved in vigilance and automatic processing. The chronicity of such responses may have detrimental consequences for health, cognitive, and learning development. Thus, any effort aimed at optimizing child development and education should consider the importance of understanding stress regulation in children.

Current studies continue to advance our understanding of the mechanisms through which experience and environmental influences interact with genes—especially with DNA biochemical markers and histone proteins that regulate gene activity—that could be modified by early experiences. Preliminary evidence from animal and human studies of maternal care, caregiver maltreatment, mother-infant separation, and prenatal stress suggests that early environmental influences could produce lasting epigenetic modifications, stable changes in nervous system gene activity, and learning and memory processing (Roth and Sweat 2011; Zhang and Meany 2010). Researchers have recently incorporated evidence of the modulation of epigenetic mechanisms during early development in different rearing conditions (e.g., disparate SES, stress exposure) into this research agenda. For instance, Essex and colleagues (2013) examined differences in adolescent DNA methylation in relation to parents' reports of adversity during their own childhood. They found that maternal stressors in infancy and parental stressors in preschool periods predicted differential methylation. In addition, recent cumulative evidences have suggested differential susceptibility to rearing environment depending on dopamine-related genes (Bakermans-Kranenburg and Van Ijzendoorn 2011).

Recently, studies have begun to apply these frameworks to analyse the association between dopaminergic polymorphisms and educational achievement (Beaver, Wright, DeLisi, and Vaughn 2012). Although we should explore many conceptual and methodological issues, the epigenetic approach supports the notion that epigenetic changes are involved, at least partially, the long-term impact of early experiences, and that pharmacological and behavioural means may potentially reverse or modify epigenetic alterations. Thus, our understanding of the role of the epigenome in behavioural modifications driven by early experiences could contribute to our understanding of childhood poverty and brain development. However, genetic polymorphisms in humans should be cautiously analysed because similar experiences could produce different outcomes in different people, which adds another level of complexity to the study of how behaviour is modulated by early experiences.

Where we are, where we should go

Available evidence from neuroscientific studies indicates that the influences of poverty on brain development are heterogeneous and modulated by stage of development, neural network, and level of organization (i.e., molecular, neural activation, cognition). In this modulation, the neural systems most sensitive to poverty seem to be those involved in cognitive control, language, and learning processing. In addition, the hypothesized mechanisms of mediation of such influences involve a dynamic system of individual and environmental factors, in which language exposure and stress regulation are two of the most important. In general, research questions—and, therefore, the interpretation of data obtained by the applied molecular, behavioural, and neuroimaging techniques seem to focus on the comparison of performance and degree of neural activation. In addition, most of the evidence is still based on cross-sectional or short-longitudinal designs. This sometimes leads to the mistaken notion that poverty is associated with cognitive deficits (e.g., Reardon 2015), but the trajectories of typical and atypical neural development in disparate socioeconomic contexts generate different degrees of brain plasticity. In such a context, the consideration of the sensitive periods and the potential for change of plasticity through interventions (e.g., Bavelier et al. 2010), have implications for those disciplines addressing childhood poverty based on the notion that the impacts are permanent and irreversible (Georgieff, Brunette, and Tran 2015).

The idea that the impacts of poverty are not necessarily immutable helps us to understand the ethical and moral responsibilities of communities in modifying such impacts (Lipina and Evers 2017). Approaching the mediation of childhood poverty by taking into consideration neural and cognitive development hypothesized by contemporary neuroscience of poverty (i.e., language exposure and stress regulation) may be a positive approach to many aims included in the SDGs.

The neuroscientific approach helps us to understand more specifically the extent of the impacts of social and material deprivation (Stephens, Markus, and Phillips 2014) and the possibilities for preventive interventions to protect human development (Shonkoff, Boyce, and McEwen 2009). Thus, neuroscience should actively participate in the ethical discussion of poverty, thus enhancing debate about basic moral rights and facilitating their exercise (Lipina and Evers 2017; Lipina and Segretin 2015b). Access to adequate material—symbolic and affective resources—from the prenatal stage onward encourages a child's emotional and intellectual development in different contexts, such as home and school. It further promotes full social and educational inclusion, and basic human rights, which have been considered by different disciplines, including education, psychology, and neuroscience. However, a need still exists for a specific (neuroscientific) critique on how to conceptualize the childhood experience of poverty, to include and adjust the implications of poverty's impacts and mechanisms according to different aspects of cognitive development and ecological multilevel perspectives (Duncan and Magnuson 2012; Lipina 2016; Lipina et al. 2011; Ursache and Noble 2016). Although theorists have not yet developed this critique, neuroscientific evidence on the impact of poverty—and the progression of that impact—during a child's development helps us to understand poverty as a much more complex and dynamic phenomenon than do the definitions proposed by other social and human scientific disciplines.

Future directions in this area of research include:

(a) Identifying mechanisms through which the different dimensions of childhood poverty and interventions exert their influences on specific neural systems in distinct stages of development.
(b) Prioritizing interdisciplinary efforts that could generate innovative means to conduct basic and applied research, which should involve at least the areas of nutrition, emotional, cognitive, and language development; early care environments; parenting, and schooling.
(c) Targeting interventions based on the consideration of individual differences in the neural efficiency of different networks.
(d) Creating innovative methods to apply in policy efforts.
(e) Sustaining and disseminating basic ethical principles about the mutability of the impacts of poverty.

References

Avants, B. B., Hackman, D. A., Betancourt, L. M., Lawson, G. M., Hurt, H., & Farah, M. J. (2015). Relation of childhood home environment to cortical thickness in late adolescence: Specificity of experience and timing. *PLoS One, 10,* e0138217. doi:10.1371/journal.pone.0138217.

Bakermans-Kranenburg, M. J., & Van Ijzendoorn, M. H. (2011). Differential susceptibility to rearing environment depending on dopamine-related genes: New evidence and a meta-analysis. *Development and Psychopathology, 23,* 39–52. doi:10.1017/S0954579410000635.

Barker, R. G. (1968). *Ecological psychology*. Stanford, CA: Stanford University Press.

Bavelier, D., Levi, D. M., Li, R., Dan, Y., & Hensch, M. P. (2010). Removing brakes on adult brain plasticity: From molecular to behavioral interventions. *Journal of Neuroscience, 30,* 14964–14971. doi:10.1523/JNEUROSCI.4812-10.2010.

Beaver, K. M., Wright, J. P., DeLisi, M., & Vaughn, M. G. (2012). Dopaminergic polymorphisms and educational attainment: Results from a longitudinal sample of Americans. *Developmental Psychology, 48,* 932–938. doi:10.1037/a0026313.

Beddington, J., Cooper, C. L., Field, J., Goswami, U., Huppert, F. A., Jenkins, R., et al. (2008). The mental wealth of nations. *Nature, International Weekly Journal of Science, 455,* 1057–1060. doi:10.1038/4551057a.

Betancourt, L. M., Avants, B., Farah, M. J., Brodsky, N. L., Wu, J., Ashtari, M., et al. (2015). Effect of socioeconomic status (SES) disparity on neural development in female African-American infants at age 1 month. *Developmental Science*. doi:10.1111/desc.12344.

Blair, C. (2010). Stress and the development of self-regulation in context. *Child Development Perspectives, 4,* 181–188. doi:10.1111/j.1750-8606.2010.00145.x.

Blair, C., & Raver, C. C. (2012). Child development in the context of adversity: Experiential canalization of brain and behavior. *American Psychologist, 67,* 309–318. doi:10.1037/a0027493.

Blair, C., & Raver, C. C. (2016). Poverty, stress, and brain development: New directions for prevention and intervention. *Academic Pediatrics, 16,* S30–S36. doi:10.1016/j.acap.2016.01.010.

Blair, C., Granger, D. A., Willoughby, M., Mills-Koonce, R., Cox, M., Greenberg, M. T., et al. (2011). Salivary cortisol mediates effects of poverty and parenting on executive functions in early childhood. *Child Development, 82,* 1970–1984. doi:10.1111/j1467-8624.2011.01643.x.

Bornstein, M. H., Putnick, D. L., Lansford, J. E., Deater-Deckard, K., & Bradley, R. H. (2015). A developmental analysis of caregiving modalities across infancy in 38 low- and middle-income countries. *Child Development, 86,* 1571–1587. doi:10.1111/cdev.12402.

Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Review of Psychology, 53,* 371–399.

BDCG [Brain Development Cooperative Group] (2012). Total and regional brain volumes in a population-based sample from 4 to 18 years: The NIH MRI study of normal brain development. *Cerebral Cortex, 22,* 1–12. doi:10.1093/cercor/bhr018.

Brito, H. H., & Noble, K. G. (2014). Socioeconomic status and structural brain development. *Frontiers in Neuroscience, 8,* 276. doi:10.3389/fnins.2014.00276.

Brody, G. H., Dorsey, S., Forehand, R., & Armistead, L. (2002). Unique and protective contributions of parenting and classroom processes to the adjustment of African American children living in single-parent families. *Child Development, 73,* 274–286. doi:10.1111/1467-8624.00405.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design*. Cambridge, MA: Harvard University Press.

Brooks-Gunn, J., & Duncan, G. J. (1997). The effects of poverty on children. *Future of Children, 7,* 55–71.

D'Angiulli, A., Van Roon, P. M., Weinberg, J., Oberlander, T. F., Grunau, R. E., Hertzman, C., et al. (2012). Frontal EEG/ERP correlates of attentional processes, cortisol, and motivational states in adolescents from lower and higher socioeconomic status. *Frontiers in Human Neuroscience, 6,* 306. doi:10.3389/fnhum.2012.00306.

D'Angiulli, A., Lipina, S. J., & Olesinska, A. (2012). Explicit and implicit issues in the developmental cognitive neuroscience of social inequality. *Frontiers in Human Neuroscience, 6,* 254. doi:10.3389/fnhum.2012.00254.

Demir, Ö. E., & Küntay, A. C. (2014). Cognitive and neural mechanisms underlying socioeconomic gradients in language development: New answers to old questions. *Child Development Perspectives, 2,* 113–118. doi:10.1111/cdep.12069.

Donald, K. A., Eastman, E., Howells, F. M., Adnams, C., Riley, E. P., Woods, R. P., et al. (2015). Neuroimaging effects of prenatal alcohol exposure on the developing human brain: A magnetic resonance imaging review. *Acta Neuropsychiatrica, 27,* 251–269. doi:10.1017/neu.2015.12.

Dornan, P., & Woodhead, M. (2015). *How inequalities develop through childhood: Life course evidence from the Young Lives cohort study*. Discussion Paper 2015-01. Florence: UNICEF Office of Research.

Duncan, G. J., & Magnusson, K. (2012). Socioeconomic status and cognitive functioning: Moving from correlation to causation. *Willey Interdisciplinary Reviews. Cognitive Science, 3,* 377–386. doi:10.1002/wcs.1176.

Eamon Keegan, M. (2002). Effects of poverty on mathematics and reading achievement of young adolescents. *Journal of Early Adolescence, 22,* 49–74. doi:10.1177/0272431602022001003.

Essex, M. J., Boyce, W. T., Hertzman, C., Lam, L. L., Armstrong, J. M., Neumann, S. M., et al. (2013). Epigenetic vestiges of early developmental adversity: Childhood stress exposure and DNA methylation in adolescence. *Child Development, 84,* 58–75. doi:10.1111/j.1467-8624.2011.01641.x.

Evans, G. W., Dongping, L., & Whipple, S. S. (2013). Cumulative risk and child development. *Psychological Bulletin, 139,* 1342–1396. doi:10.1037/a0031808.

Farah, M. J., Shera, D. M., Savage, J. H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., et al. (2006). Childhood poverty: Specific associations with neurocognitive development. *Brain Research, 1110,* 166–174.

Fernald, L. C. H., & Gunnar, M. R. (2009). Poverty-alleviation program participation and salivary cortisol in very low-income children. *Social Science & Medicine, 68,* 2180–2189. doi:10.1016/j.socscimed.2009.03.032.

Foresight Mental Capital and Wellbeing Project (2008). *Systems maps*. London: The Government Office for Science.

Ganzel, B., Morris, P., & Wethington, E. (2010). Allostasis and the human brain: Integrating models of stress from the social and life sciences. *Psychological Review, 117,* 134–174. doi:10.1037/a0017773.

Georgieff, M. K., Brunette, K. E., & Tran, P. V. (2015). Early life nutrition and neural plasticity. *Development and Psychopathology, 27,* 411–423. doi:10.1017/S0954579415000061.

Gianaros, P. J., & Hackman, D. (2013). Contribution of neuroscience to the study of socioeconomic health disparities. *Psychosomatic Medicine, 75,* 1–6. doi:10.1097/PSY.0b013e3182a5f9c1.

Grandjean, P., & Landrigan, P. J. (2014). Neurobehavioural effects of developmental toxicity. *Lancet Neurology, 13,* 330–338. doi:10.1016/S1474-4422(13)70278-3.

Hackman, D. A., & Farah, M. J. (2009). Socioeconomic status and the developing brain. *Trends in Cognitive Sciences, 13,* 65–73. doi:10.1016/j.tics.2008.11.003.

Hackman, D. A., Farah, M. J., & Meany, M. J. (2010). Socioeconomic status and the brain: Mechanistic insights from human and animal research. *Nature Reviews Neuroscience, 11,* 651–659. doi:10.1038/nrn2897.

Hackman, D. A., Gallop, R., Evans, G. W., & Farah, M. J. (2015). Socioeconomic status and executive function: Developmental trajectories and mediation. *Developmental Science, 18,* 686–702. doi:10.1111/desc.12246.

Hair, N. L., Hanson, J. L., Wolfe, B. L., & Pollak, S. D. (2015). Association of child poverty, brain development, and academic achievement. *JAMA Pediatrics, 169,* 822–829. doi:10.1001/jamapediatrics.2015.1475.

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore, MD: Paul H. Brookes Publishing Company.

Hirsh-Pasek, K., Adamson, L. B., Bakeman, R., Tresch Owen, M., Golinkoff, R. M., Pace, A., et al. (2015). The contribution of early communication quality to low-income children's language success. *Psychological Science, 26,* 1071–1083. doi:10.1177/0956797615581493.

Hoff, E. (2006). How social contexts support and shape language development. *Developmental Review, 26,* 55–88. doi:10.1016/j.dr.2005.11.002.

Johnson, S. B., Riis, J. L., & Noble, K. G. (2016). State of the art review: Poverty and the developing brain. *Pediatrics, 137,* pjj: e20153075. doi:10.1542/peds.2015-3075.

Karatoreos, I. N., & McEwen, B. S. (2013). Annual research review: The neurobiology and physiology of resilience and adaptation across the life course. *Journal of Child Psychology and Psychiatry, 54*, 337–347. doi:10.1111/jcpp.12054.

Kim, P., Evans, G. W., Angstadt, M., Ho, S. S., Sripada, C. S., Swain, J. E., et al. (2013). Effects of childhood poverty and chronic stress on emotion regulatory brain function in adulthood. *Proceedings of the National Academy of Sciences of the United States of America, 110,* 18442–18447. doi:10.1073/pnas.1308240110.

Lipina, S. J. (2016). Critical considerations about the use of poverty measures in the study of cognitive development. *International Journal of Psychology*. doi:10.1002/ijop.12282.

Lipina, S. J. (2014). Biological and sociocultural determinants of neurocognitive development: Central aspects of the current scientific agenda. In A. Battro & I. Potrykus (Eds.), *Bread and brain, education and poverty* (pp. 1–30). Vatican City: Pontifical Academy of Sciences.

Lipina, S. J., & Colombo, J. A. (2009). *Poverty and brain development during childhood: An approach from cognitive psychology and neuroscience*. Washington, DC: American Psychological Association.

Lipina, S. J., & Evers, K. (2017). Neuroscience of childhood poverty: Evidence of impacts and mechanisms as vehicles of dialog with ethics. *Frontiers in Psychology, 8*(61). doi:10.3389/fpsyg.2017.00061.

Lipina, S. J., & Segretin, M. S. (2015). 6000 días más: Evidencia neurocientífica acerca del impacto de la pobreza infantil1 [6000 more days: Neuroscientific evidence about the impact of childhood poverty]. *Psicología Educativa, 21*(107), 116. doi:10.1016/j.pse.2015.08.003.

Lipina, S. J., Segretin, M. S., Hermida, M. J., Prats, L., Fracchia, C., & Colombo, J. A. (2013). Linking childhood poverty and cognition: Individual and environmental predictors of non-verbal executive control in an Argentine sample. *Developmental Science, 16,* 697–707. doi:10.3389/fpsyg.2014.00205.

Lipina, S. J., Simonds, J., & Segretin, M. S. (2011). Recognizing the child in child poverty. *Vulnerable Children and Youth Studies, 6,* 8–17. doi:10.1080/17450128.2010.521598.

Lupien, S. J., McEwen, B. S., Gunnar, M. R., & Heim, C. (2009). Effects of stress throughout the lifespan on the brain, behaviour and cognition. *Nature Reviews Neuroscience, 10,* 434–445. doi:10.1038/nrn2639.

Mackey, A. P., Finn, A. S., Leonard, J. A., Jacoby-Senghor, D. S., West, M. R., Gabrieli, C. F. O., et al. (2015). Neuroanatomical correlates of the income-achievement gap. *Psychological Science, 26,* 925–933. doi:10.1177/0956797615572233.

Maholmes, V., & King, R. B. (2012). *The Oxford Handbook of poverty and child development*. Oxford: Oxford University Press.

McEwen, B. S., & Gianaros, P. J. (2010). Central role of the brain in stress and adaptation: Links to socioeconomic status, health, and disease. *Annals of the New York Academy of Sciences, 1186,* 190–222. doi:10.1111/j.1749-6632.2009.05331.x.

McLaughlin, K. A., & Sheridan, M. A. (2016). Beyond cumulative risk: A dimensional approach to childhood adversity. *Current Directions in Psychological Science, 25,* 239–245.

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H. L., et al. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences of the United States of America, 108,* 2693–2698. doi:10.1073/pnas.1010076108.

NICHD [National Institute of Child & Human Development Early Child Care Research Network] (2005). Duration and developmental timing of poverty and childreńs cognitive and social development from birth through third grade. *Child Development, 76,* 795–810.

Noble, K. G., Houston, S. M., Brito, N. H., Bartsch, H., Kane, E., Kuperman, J. M., et al. (2015). Family income, parental education and brain structure in children and adolescents. *Nature, International Weekly Journal of Science, 18,* 773–778. doi:10.1038/nn.3983.

Noble, K. G., Norman, M. F., & Farah, M. J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science, 8,* 74–87.

Odgers, C. L. (2015). Income inequality and the developing child: Is it all relative? *American Psychologist, 70,* 722–731. doi:10.1037/a0039836.

Pavlakis, A. E., Noble, K., Pavlakis, S. G., Ali, N., & Frank, Y. (2015). Brain imaging and electrophysiology biomarkers: Is there a role in poverty and education outcome research? *Pediatric Neurology, 52,* 383–388. doi:10.1016/j.pediatrneurol.2014.11.005.

Peretz, I., & Zatorre, R. J. (2005). Brain organization for music processing. *Annual Review of Psychology, 56,* 89–114. doi:10.1146/annurev.psych.56.091103.070225.
Perkins, S. C., Finegood, E. D., & Swain, J. E. (2013). Poverty and language development: Roles of parenting and stress. *Innovation in Clinical Neuroscience, 10,* 10–19.
Piccolo, L. R., Merz, E. C., He, X., Sowell, E. R., & Noble, K. G. (2016). Age-related differences in cortical thickness vary by socioeconomic status. *PLoS One, 11,* e0162511. doi:10.1371/journal.pone.0162511.
Posner, M. I., & Raichle, M. E. (1994). *Images of mind*. New York: Scientific American Library.
Raizada, R. D. S., & Kishiyama, M. M. (2010). Effects of socioeconomic status on brain development, and how cognitive neuroscience may contribute to leveling the playing field. *Frontiers in Human Neuroscience, 4,* 3. doi:10.3389/neuro.09.003.2010.
Reardon, S. (2015). Poverty shrinks brains from birth. *Nature, International Weekly Journal of Science*. doi:10.1038/nature.2015.17227.
Roth, T. L., & Sweatt, J. D. (2011). Epigenetic mechanisms and environmental shaping of the brain during sensitive periods of development. *Journal of Child Psychology and Psychiatry, 52,* 398–408. doi:10.1111/j.1469-7610.2010.02282.x.
Scott, M. M. (2005). A powerful theory and a paradox: Ecological psychologists after Barker. *Environment and Behavior, 37,* 295–329. doi:10.1177/0013916504270696.
Sheridan, M. A., & McLaughlin, K. A. (2014). Dimensions of early experience and neural development: Deprivation and threat. *Trends in Cognitive Sciences, 18,* 580–585. doi:10.1016/j.tics.2014.09.001.
Sheridan, M. A., Sarsour, K., Jutte, D., D'Esposito, M., & Boyce, W. T. (2012). The impact of social disparity on prefrontal function in childhood. *PLoS ONE, 7,* e35744. doi:10.1371/journal.pone.0035744.
Shonkoff, J. P., Boyce, W. T., & McEwen, B. S. (2009). Neuroscience, molecular biology, and the childhood roots of health disparities: Building a new framework for health promotion and disease prevention. *JAMA, 301,* 2252–2259. doi:10.1001/jama.2009.754.
Shonkoff, J. P., Garner, A. S., & Committee on Psychosocial Aspects of Child and Family Health, Committee on Early Childhood, Adoption, and Dependent Care, & Section on Developmental and Behavioral Pediatrics (2012). The lifelong effects of early childhood adversity and toxic stress. *Pediatrics, 129,* e232–e246. doi:10.1542/peds.2011-2663.
Sirois, S., Spratling, M., Thomas, M. S., Westermann, G., Mareschal, D., & Johnson, M. J. (2008). Précis of neuroconstructivism: How the brain constructs cognition. *Behavioral and Brain Sciences, 31,* 321–331. doi:10.1017/S0140525X0800407X.
Sperber, D., & Hirschfeld, L. A. (2004). The cognitive foundations of cultural stability and diversity. *Trends in Cognitive Sciences, 8,* 40–46. doi:10.1016/j.tics.2003.11.002.
Stephens, N. M., Markus, H. R., & Phillips, L. T. (2014). Social class culture cycles: How three gateway contexts shape selves and fuel inequality. *Annual Review of Psychology, 65,* 16.1–16.24. doi:10.1177/0022022114534768.
Thompson, B. L., Levitt, P., & Stanwood, G. D. (2009). Prenatal exposure to drugs: Effects on brain development and implications for policy and education. *Nature Reviews Neuroscience, 10,* 303–312. doi:10.1038/nrn2598.
Ursache, A., & Noble, K. G. (2016). Neurocognitive development in socioeconomic context: Multiple mechanisms and implications for measuring socioeconomic status. *Psychophysiology, 53,* 71–82. doi:10.1111/psyp.12547.
Wagmiller, R. L. (2015). The temporal dynamics of childhood economic deprivation and children's achievement. *Child Development Perspectives, 9,* 158–163.
Wiebe, S. A., Clark, C. A. C., De Jong, D. M., Chevalier, N., Espy, K. A., & Wakschlag, L. (2015). Prenatal tobacco exposure and self-regulation in early childhood: Implications for developmental psychopathology. *Development and Psychopathology, 27,* 397–409. doi:10.1017/S095457941500005X.
Yoshikawa, H., Aber, J. L., & Beardslee, W. R. (2012). The effects of poverty on the mental, emotional, and behavioral health of children and youth. *American Psychologist, 67,* 272–284. doi:10.1037/a0028015.
Zhang, T. Y., & Meaney, M. J. (2010). Epigenetics and the environmental regulation of the genome and its function. *Annual Review of Psychology, 61,* 439–466. doi:10.1146/annurev.psych.60.110707.163625.

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