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IMPLICATIONS OF THE NEUROSCIENTIFIC EVIDENCE ON CHILDHOOD POVERTY

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Introduction

Over the past two decades, research on childhood poverty has begun to provide evidence that contributes to advancing the understanding of how early adversity associated with material and social deprivation impacts brain development. When such evidence is used in other disciplinary contexts, references are typically made to early brain development as a predictor of either adaptive behaviors and economic productivity during adult life (e.g., Black el al., 2017) or of the impossibility of such achievements due to the supposed immutability of the long-term negative impacts of childhood poverty on brain development (Nilsen, 2017). These types of statements, which have not only scientific but also policy implications, need to be analyzed adequately in light of the available evidence, as they could lead to misconceptions and overgeneralizations that have the potential to affect investment criteri a, as well as the design, implementation, and evaluation of actions in the field of early childhood.

Consequently, in addition to the need to review the available evidence we consider it important to create opportunities for critical reflection that contribute to understanding the implications of this evidence. This chapter addresses three aspects that we consider essential for these aims: (1) a brief review of the basic concepts of human development proposed by contemporary developmental science; (2) a synthesis of the neuroscientific evidence from poverty studies; and (3) a reflection on the implications of such evidence for the continuity of the construction of knowledge in the area, as well as for the design, implementation, and evaluation of interventions or policies.

Assumptions about human development

Systemic-relational approaches

Contemporary theories of human development are framed within meta-theoretical frameworkds called relational development systems (RDS), which propose that changes that occur during the life cycle occur through relationships of mutual influence between people and their developmental contexts (Overton & Molenaar, 2016). This type of approach deals with analyzing: (a) processes (i.e., changes in developmental systems); (b) experiences (i.e., developmental processes occur over time, which implies that they take the form of states of potentiality and action); (c) systems (i.e., social and cultural contexts in which developmental processes occur); (d) relational analysis of mutual influences between individuals and contexts; and (e) multiplicity of perspectives and forms of explanation. Consequently, what characterizes development is the permanent co-evolution or transformation of the biological and social systems it involves, so that the directionality of the trajectories is variable between individuals and populations, within the limits imposed by the regularities of species.

Likewise, RDS approaches deal with analyzing different levels of organization, from the biological to the cultural (Barker, 1965; Bronfenbrenner, 1987; Lerner, 2018), so that the interactions between people and contexts are both independent and interdependent (Figure 1). The individual is considered a complex, active, and self-regulating agent. Given such a self-regulatory characteristic, any notion of adaptation necessarily requires considering contextual meanings: there would be no adaptation processes independent of the contexts in which they occur - which includes the belief systems, norms, and values that characterize every culture.

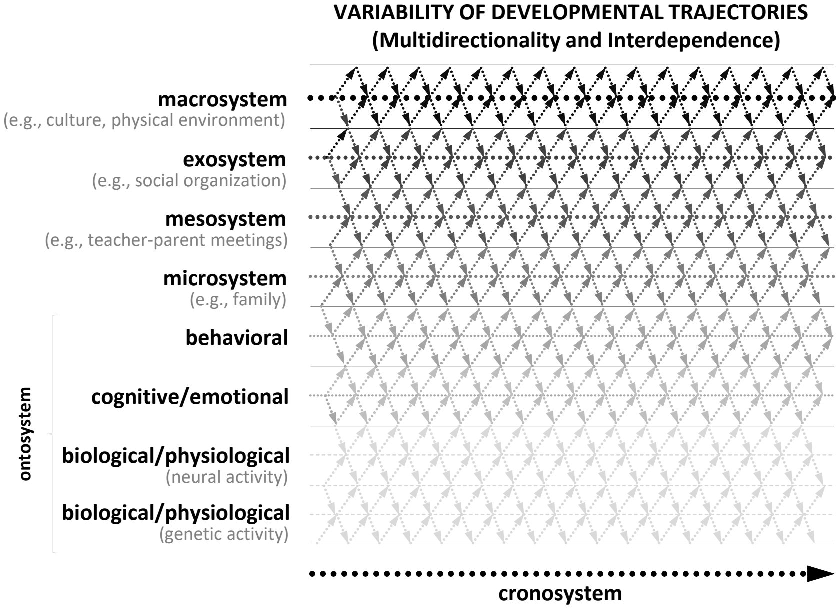

Figure 1 – Schematic representation of an RDS model that theoretically illustrates the matrix of possible trajectories, relationships and interactions of developmental events considering different levels of organization defined in terms of contexts according to the theory of Urie

Bronfenbrenner (i.e., ontosystemic, microsystemic, mesosystemic, exosystemic, macrosystemic). For the same individual, at each level of organization a trajectory of events could be drawn that would be idiosyncratic with respect to the mechanisms that occur there; and at the same time interdependent of the trajectories at other levels (inspired by Figure 2.1 of Lerner, 2018).

Neural development

The initial organization of the nervous system follows a sequence of adaptive processes of generation, connection, and elimination of nerve cells and connections. The initial phases of nerve cell generation, migration, and subsequent differentiation are followed by dendritic growth, synapse formation, and elimination. The further development and refinement of neural networks almost always involves the removal of neurons through a programmed process called apoptosis. At the end of these initial processes of organization of the nervous system, about half of the neurons are finally eliminated. The evidence available from five decades of research indicates that the timing of such processes of overproduction and pruning of synaptic contacts varies in different areas of the cerebral cortex, continuing through at least the second decade of life (Bathelt et al., 2018; Brown, 2017; Ismail et al., 2017; Perez et al., 2016; Schmitt et al., 2017).

In studies with animal models, the presence or absence of material, sensory, and social stimuli in developmental contexts has been repeatedly associated with changes in different aspects of the structure and functioning of the nervous system during its development. Such changes, which occur due to the adaptive nature of the components and connections of the nervous system, have been documented at different levels of organization, from the molecular to the structure and function of different neural networks (Caroni et al., 2012; Grossman et al ., 2003). In humans, these development processes are modulated by a great diversity of molecular, cellular, psychological, social, and cultural mechanisms.

During neural development, there are moments of maximum organization of different functions that are called *critical or sensitive periods*, and that occur at different times for different neural networks. If during such critical periods an alteration occurs, either positive or negative, it will tend to be incorporated into the neural function in a permanent or semi-permanent way, limiting the opportunities for its reorganization. Many of these periods take place early in development, particularly during the perinatal phase and in the first months of life. In the case of more complex processes such as emotional, cognitive, and learning skills, such organization depends on the progressive integration of different neural networks, which process more than one modality of information and which take place at different times during at least the two first decades of life. At the neural level, this integration requires different types of nutrients and experiences that include but extend well beyond the first thousand days (Figure 2). From the contemporary perspective of neural development, the first thousand days are extremely insufficient to predict the development of a typical human brain. In summary, the available neuroscientific knowledge allows us to affirm that, from conception and throughout life, the nervous system is organized and modified based on the dynamic interaction between individual and contextual characteristics of each person.

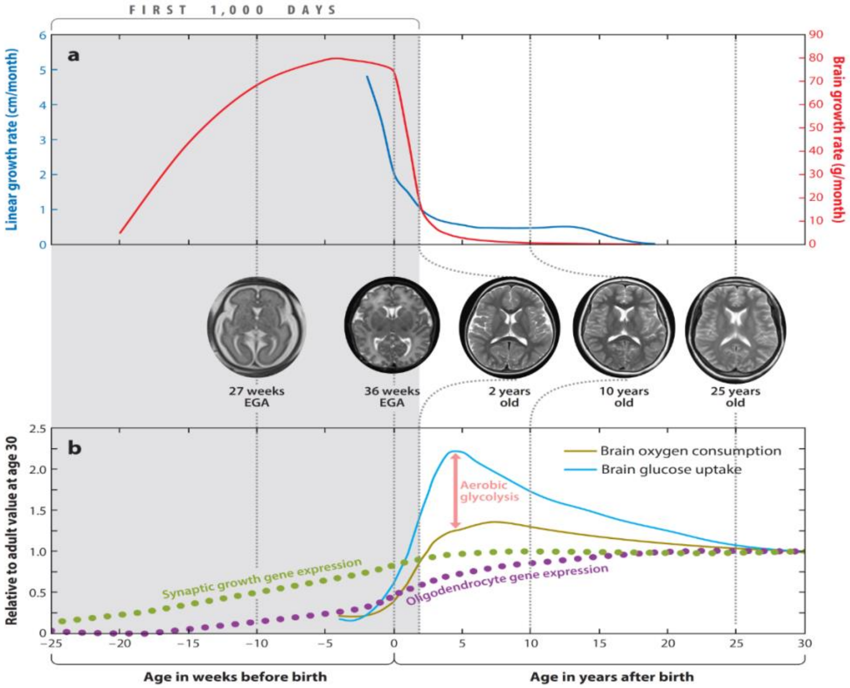

Figure 2 - Significant changes in the human brain from conception to adulthood. The human brain gains much of its mass and structure during the first thousand days, which begin at conception and end at approximately 2 years of age. (a) The brain growth rate (red line) is very high during this period of time, and then falls rapidly as childhood begins. Structurally, the brain also begins to closely resemble the adult brain at 2 years of age. Metaphorically, the foundation, structure, and framework of the construction process have been largely completed. However, much more work needs to be done to build, reshape, and isolate the myriad of connections within the brain. (b) Gene expression related to synaptic growth peaks shortly after the first 1,000 days, but remains high into adulthood (green dotted line). The genetic expression related to myelination increases later in time (purple dotted line). Both the consumption of oxygen in the brain (green solid line) and glucose (blue light solid line) continue to increase and reach their maximum level in early childhood, gradually decreasing to adult levels during the rest of childhood and adolescence. In particular, the gap between glucose and oxygen consumption widens: aerobic glycolysis at 5 years represents approximately 30% of the glucose consumption rate of the human brain

compared to approximately 10% at the age of 30. These characteristics point to the important metabolic requirements of the brain that continue well beyond the first 1,000 days, advocating an expanded perspective on the nutritional requirements of the developing human brain. Abbreviation: EGA, estimated gestational age. This figure corresponds to the work by Goyal et al., 2018, and authorized for reproduction in this chapter by its authors.

Summary of neuroscientific evidence on childhood poverty [3]

Studies on association between poverty and neural events

The neuroscientific study of childhood poverty is a recently developed area (Farah, 2017, 2018; Lipina & Colombo, 2009). Since the mid-1990s, different researchers began to compare the performance of children from homes with and without poverty in tasks with self-regulatory, phonological processing, and episodic memory demands. Neuroimaging and behavioral genetics technologies were gradually incorporated into such efforts. The first investigations with this type of information began to be published only in the 2000s. Until mid-2019, the number of published studies presenting empirical evidence generated with neuroimaging did not exceed the number of 200 articles in two decades. On the other hand, approximately 80% of such evidence was generated in the United States, 77% of the studies applied cross-sectional designs, 50% of articles were based on anatomical information, and less than 5% addressed issues related to learning

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[3] In this chapter we will not address specific questions inherent in the conceptual definitions and indicators of poverty -a topic that raises different debates and complexities of analysis in different human and social disciplines for decades- for which we will refer to the term poverty to all the forms of material and social deprivation derived from processes of inequity. Readers interested in delving into such specific questions will find more than two hundred definitions and indicators in the work by Spickler and colleagues (2009), which contains definitions and paradigms that have generated in the social, human, and health sciences since the late nineteenth century.

(Farah, 2018; Lipina, 2017a). This publication profile does not in any way detract from the area's effort to contribute to knowledge. However, it is important to understand what kinds of statements can and cannot be supported, since an important part of the contemporary narrative on neural development does not incorporate the update of the evidence generated during the 1990s (Lipina, 2016, 2017c) .

The main current questions in the area focus on some topics already discussed in the fields of developmental psychology, cognitive psychology, and health sciences for much of the 20th century, especially with respect to the effects and mechanisms of mediation at the level of behavioral organization. However, the innovative aspect of neuroscientific approaches in childhood poverty studies is the consideration of components, events, and mechanisms related to processes of cognitive and emotional self-regulation, phonological processing, memory, and learning, at the neural level of organization (D´Angiulli et al., 2014; Farah, 2017, 2018; Johnson et al., 2016; Lipina, 2016, 2017b; Pakulak et al., 2018; Ursache & Noble, 2016) [4].

At the behavioral level of organization, evidence indicates that poverty is associated with low performance on tasks with demands for cognitive control and metacognitive processes (e.g., executive functions and theory of mind), phonological processing, episodic memory, and learning, and these effects are observed at least through the first two decades of life (Farah, 2017; Johnson et al., 2016; Lipina & Colombo, 2009). In some studies, it has been

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[4] The influences of prenatal and postnatal exposure to malnutrition, legal and illegal drugs, and environmental toxic agents on neural development are aspects related, although not exclusively so, to the experience of childhood poverty. For this reason, we will not address this evidence in this chapter, as we will focus our attention on specific studies in neuroscience and childhood poverty. However, readers who wish to access such information may consult the works of Donald et al. (2015), Georgieff et al. (2015), Grandjean and Landrigan (2014), Thompson et al. (2009), and Wiebe et al. (2015).

verified that the association of exposure to poverty with performance in some cognitive tasks is neither similar across all domains, nor uniform for all ages (e.g., Farah et al., 2006; Lipina et al., 2013; Noble, Norman, & Farah, 2005). This means that there are children living in conditions of adversity due to poverty who have typical performances for their age in some cognitive domains, and that this may vary according to their age and the type of test administered. This is to be expected, since both poverty and self-regulatory development are complex processes that involve multiple interdependent factors.

Evidence at the behavioral level of organization is invaluable to understanding the associations between poverty and self-regulatory development, episodic memory, and learning. However, behavioral studies do not allow inferences to be drawn about the level of neural organization. This requires specific technical and methodological approaches that began to be implemented in the early 2000s, when researchers began to use techniques such as structural magnetic resonance imaging (MRI), magnetic resonance spectroscopy (MRS), and functional magnetic resonance imaging (fMRI), as well as electroencephalography (EEG) and event-related potential (ERP) techniques, and structural and functional infrared spectroscopy (NIRS and fNIRS).

These techniques have been used to obtain different types of information. With MRI, it is possible to obtain high-resolution anatomical images that allow structural aspects of the brain to be measured, such as thickness, surface or volume of gray and white matter, as well as the concentration of neurotransmitters. The association of this type of information with that of performance in cognitive or learning tasks, for example, can only be made through correlational analyses, which are associative and do not account for causal relationships. Beyond this limitation, in this preliminary stage of the studies of the area, such information is valuable to begin to understand phenomena of neural and behavioral plasticity that should continue to be deepened with new research that improves knowledge about the mechanisms involved (Farah, 2018; Lipina, 2016; Pakulak et al., 2018). It is also important to note that information on thickness, surface, and volume of the cerebral cortex obtained with MRI techniques corresponds to a macroscopic dimension of analysis. This means that it does not provide information on molecular and cellular events that also participate in the mechanisms of association between poverty and neural development. Functional MRI techniques allow for the acquisition of information on the neural resources involved during the performance of tasks, based on the increase in neural activity due to oxygen consumption. Electroencephalographic techniques allow for the acquisition of information on neuronal electrical activity in the resting state (EEG) or in response to specific stimuli (ERP). NIRS techniques are based on the detection of near infrared light through the skull, which permits non-invasive assessment of brain structure and, via detection of changes in blood oxygenation associated with neural activity in a manner similar to fMRI, brain function.

These different neuroimaging techniques vary in the nature and quality of information they each provide with respect to spatial and temporal resolution. In the case of fMRI, it is important for the non-expert reader to understand that in images where color is used to denote areas of greater activity, these colors are assigned by the researchers after carrying out different statistical analyses. In turn, all the techniques require a great deal of filtering of noisy signals, which involves specific conceptual and methodological criteria for decision-making processes. In other words, such images are in part the construction of researchers. With the exception of MRS or high resolution equipment, in general these techniques provide information at the macroscopic level.

A summary of the evidence from MRI studies indicates that family income and maternal education have been associated with changes in the volume of the hippocampus and the amygdala between the ages of 4 and 22 years. On the other hand, maternal educational level has been associated with a larger range of outcomes, including differences in the following: changes in the cortical thickness and the volume of the prefrontal, parietal, and occipital neural networks between the ages of 4 and 18 years; the rate of brain growth and in the volume of frontal and parietal neural networks in children from 1 month to 4 years of age; the connectivity between frontal and parietal neural networks between 12 and 24 years of age; and the trajectories of the development of neural networks of the hippocampus in girls and adolescents from 9 to 15 years old. Finally, parental income and education have been associated with changes in the patterns of connectivity between different cortical neural networks and the striatum between the ages of 6 and 17 (Avants et al., 2015; Betancourt et al., 2015; Brito et al., 2017; Ellwood-Lowe et al., 2018; Hair et al., 2015; Mackey et al., 2015; Marshall et al., 2018; Noble et al., 2015; Piccolo et al., 2016; Sripada et al., 2014; Ursache et al., 2016; Weissman et al., 2018). In some of these studies, structural changes were also associated with performance on tasks with demands for cognitive control, language, and learning (e.g., Brito et al., 2017; Hair et al., 2015; Mackey et al., 2015; Noble, et al., 2015; Ursache et al., 2016).

Only recently has MRI evidence begun to be generated on the association between poverty and neural development in adult populations without histories of neurological or psychiatric disorders. For instance, McLean and colleagues (2012) found that the history of childhood poverty in terms of material deprivation was associated with changes in the concentration of N-Acetyl-aspartate (NAA), a molecular marker associated with neuronal integrity, in neural networks of the hippocampus of adults from 35 to 65 years. Chan and colleagues (2018) found that lower educational and occupational level in a sample of adults aged 35 to 64 years was associated with a reduction in the organization of functional brain networks and cortical thickness - such associations were present even when controlling for childhood socioeconomic status. In addition, preliminary evidence in studies with adults suggests that the processes of accumulation of adversities during the life cycle are not necessarily linear (Chan et al., 2018; Hackman & Farah, 2009).

Results from fMRI studies have found that income, maternal education, and paternal occupation were associated with changes in the activation of occipito-temporal networks during tasks with phonological processing demands in children between 4 and 8 years of age; the activation of prefrontal networks during the performance of tasks with associative learning demands in children between 4 and 8 years of age; activation of prefrontal and parietal networks during tasks with working memory and arithmetic processing demands in children between 8 and 12 years of age ; and the activation of amygdala networks during the performance of tasks in which threatening faces must be processed, in adults from 23 to 25 years old with a history of childhood poverty (Finn et al., 2016; Javanbakht et al., 2015; Noble et al., 2006; Raizada et al., 2008; Sheridan et al., 2012).

In EEG/ERP studies, evidence indicates that family income, maternal education, and paternal occupation have been associated with changes in: electrical activity during the resting state of infants between 6 and 9 months old; the ERP associated with attentional control of irrelevant information in children from 3 to 8 years of age; the electrical activity associated with the processing of speech and environmental sounds in adolescents; the frontal potentials related to the detection of errors and in theta power in children aged 16 to 18 months and 4 years; and the prediction of cognitive performance at 15 months based on electrical activity in the resting state at one month of life (Brito et al., 2016; Conejero et al., 2016; D´Angiulli et al., 2012; Skoe et al., 2013; Stevens et al., 2009; Tomalski et al., 2013).

This evidence confirms that poverty measured in terms of family income, parental education and occupation, and material deprivation - indicators that do not specifically account for everything included in the child's experience of poverty - are associated with a diverse set of structural and functional changes in the nervous system. In particular, the aspects of the nervous system most commonly implicated are related to cognitive and emotional self-regulatory processing, language, and learning. However, the correlational nature of this evidence does not allow us to infer the causal mechanisms through which such relationships occur. To a large extent, the psychological significance of such associations will need to be elucidated in future research. However, the initial interpretation of the evidence –even in the neuroscientific field- has been in the sense of attribution of a poverty deficit (e.g., D´Angiulli et al., 2012). Recent studies indicate that the neural resources involved in arithmetic and reading processes vary depending on poverty in a qualitative sense and not according to which neural networks are activated or not during their solution (Demir-Lira et al., 2016; Gullick et al ., 2016). In these studies, it was found that children living in poverty conditions exhibited expected reading and arithmetic performance for their age and that at the neural level such performance was associated with the activation of different neural networks compared to those utilized by children not living in poverty. On the other hand, evidence has also begun to suggest that the neural resources involved in solving inhibitory control, attention control, and reading tasks may be modified by interventions in children from poor homes with and without developmental disorders (Neville et al., 2013; Pietto et al., 2018; Romeo et al., 2018).

Modulation for associations by individual and contextual factors

Since the end of the 20th century, research carried out in the context of education, developmental psychology, sociology, and pediatric epidemiology has allowed the identification of mediating and moderating factors of associations between child poverty, self-regulatory development, and mental health. Among the most frequently identified factors are perinatal exposure to infections, legal and illegal drugs, environmental toxins, or malnutrition; the physical and mental health status of children from birth; the state of self-regulatory, social, and language development of controls children; the number of prenatal checkups; the security of attachment bonds with parental figures (at least in societies with western cultures); different stressors in the contexts of child care and education; the quality of stimulation of learning at home and in child care centers; the mental health and lifestyles of parents, caregivers, and teachers; teacher training and pedagogical styles; access to social security systems through health, education, and social development policies; community resources; social mobility; social, political, and economic crises; cultural norms, values, and expectations, which may eventually induce exclusion phenomena such as discrimination or stigmatization; exposure to natural disasters or the consequences of climate change; and the time and duration of exposure to different types of early adversity (for reviews, see Bradley & Corwyn, 2002; Duncan et al., 2017; Hackman et al., 2010; Lipina, 2016; Yoshikawa et al., 2012).

In addition to the accumulation of potential risk factors, it is important to consider that poverty is a complex phenomenon that can co-occur with other types of adversities, such as orphanhood and consequent institutionalization, or exposure to domestic or community violence. In this sense, it is important to differentiate experiences due to lack of material resources from those characterized by the presence of threats to physical integrity (Sheridan & McLaughlin, 2014). The current consensus in developmental science is that the association between poverty and child development is modulated at least by the accumulation of risk factors, the co-occurrence of adversities, the susceptibility of each child to contextual factors, and the timing of exposure to adversities.

Contemporary neuroscientific studies of mediators and moderators of the association between poverty and neural development are also at a preliminary stage. The evidence to date has found that socioeconomic status moderates the association between neural structures and functions and self-regulatory performance; that neural structures and functions moderate the association between the socio-economic level and self-regulatory performance; and that different risk and protective factors mediate the association between socioeconomic status and structure and neural function (Farah, 2017; Lipina, 2016). This type of evidence has generated the hypothesis that two pathways whereby childhood poverty would influence neural development during the first two decades of life are the quality of parenting environments and the regulation of the stress response (Ursache & Noble, 2016). The latter would add to evidence accumulated since the middle of the 20th century that suggests that stress regulation is one of the most important mediators of the association between poverty and emotional, cognitive, and social development (Blair & Raver, 2016; Lupien et al., 2009).

Threats, negative life events, exposure to environmental hazards, family and community violence, family separations and moves, job loss or instability, and economic deprivation occur across the socioeconomic spectrum but tend to be more prevalent in conditions of poverty (Bradley & Corwyn , 2002; Maholmes & King, 2012; Yoshikawa, Aber & Beardslee, 2012). The neural systems associated with the regulation of such types of stressors include the hypothalamic pituitary adrenal (HPA) axis, the amygdala, and the prefrontal cortex, which together interact with immune and cardiovascular systems. These systems work together to regulate the physiological and behavioral responses to stressors, contributing to the adaptation processes of each individual to their contextual circumstances. In the short term, the activation of these systems serves as an adaptive biological response against stressors. However, under continuous or chronic stress, they may be associated with physiological deregulations with the potential to affect the cardiovascular and immunological health in the medium and long term (Dornela Godoy et al., 2017; McEwen & Gianaros, 2010; Robertson et al., 2015; Sandi & Haller, 2015).

Investigations of childhood poverty have begun to study the modulation of epigenetic mechanisms during early childhood development under different rearing and socioeconomic conditions, where experiences can alter the expression of DNA. For example, Essex and colleagues (2013) analyzed differences in adolescent DNA methylation as a function of reports of adversity experiences during their own childhood. The results indicated that the presence of maternal stressors in childhood and parental stressors in when children were preschool-aged predicted differential methylation effects. The results support the hypothesis that epigenetic changes would be involved at least partially in the long-term influences of early experiences (Gray et al., 2017). This suggests that understanding the role of the epigenome in behavioral modifications associated with early life experiences could contribute to understanding the relationships between childhood poverty and neural development. At present, the evidence does not allow us to infer causality in epigenetic relationships that have been established in the neuroscientific literature regarding the association between poverty and self-regulatory development.

Neuroscientific intervention studies with children living in poverty

A recent development in this area involves the use of research designs that combine neuroscientific techniques and intervention studies with controlled designs, aimed at optimizing cognitive and language performance in populations of children from poor households[5]. To date, only three such studies have been published. The first of these studies is the work of Neville and colleagues (2013), who developed an intervention, Parents and Children Making Connections – Highlighting Attention (PCMC-A), aimed at optimizing selective attention processes for preschool-aged children living in poverty in the city of Eugene, Oregon (United States), through the weekly implementation of two intervention components for eight weeks, at school, after school hours. One component of the intervention consisted of attention training activities for children through individual and small-group games. The other component consisted of two-hour meetings with parents and caregivers, during which they discussed parenting issues, stress management, and communication strategies for the home. To complement the activities with children, families were encouraged to conduct different activities at home in order to stimulate self-regulatory behaviors in children and to reduce stress-

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[5] Neuroscientific intervention approaches aimed at analyzing levels of change (i.e., plasticity) of cognitive, language, and learning processes of populations of children with and without disorders, or early adversity problems not exclusively related to poverty (for example, maltreatment or institutionalization), began in the beginning of the last decade (Fisher et al., 2015; Lipina, 2016). This section only refers to those found exclusively with populations of children living in poor homes without identified disorders.

inducing factors in daily family communication. The researchers compared performance before and after the intervention, with that of children from the same context who participated in two other conditions (a similar intervention in which there was less emphasis on the parent training component and a business-as-usual condition with regular Head Start instruction and no additional intervention). Results showed that the children who participated in the PCMC-A program improved their cognitive performance at the behavioral level, but also at the neural level for a selective attention ERP component. Specifically, children who participated in the intervention expressed a neurophysiological pattern in which the activation of different neural resources could be differentiated for both relevant and irrelevant stimuli of the attention paradigm. The researchers also found that parents had reduced their perception of parenting stressors. In a later study, the same researchers also found that the children who benefited most from the intervention were those who had a specific polymorphism for a gene encoding serotonin transport (Isbell et al., 2018), adding evidence on the importance of considering different levels of organization, as well as the consideration of individual differences, in the impact analysis of the interventions.

The second of these studies corresponds to a computerized intervention designed by Romeo and colleagues (2018) for 6-9-year-old children with reading difficulties from different socioeconomic contexts, aimed at improving their performance in reading. After six weeks of fluency, spelling, and word reading training -implemented for four hours per day, Monday-Friday during the summer - the researchers found an increase in scores on standardized reading tasks and an increase in the thickness of neural networks involved in this type of processing (i.e., occipito-temporo-parietal), only in those children from lower SES homes.

The third of these studies was implemented by Pietto and colleagues (2018) and consisted of a computerized training aimed at optimizing cognitive control performance (i.e., inhibitory control, cognitive flexibility, working memory, planning) in 5-year-old children from lower SES homes. The training was implemented for 12 weeks, with 15-minute sessions weekly. Preliminary results showed an improvement in an ERP component related to inhibitory control processing only in the trained group.

Although in all three intervention studies described it is assumed that the implemented interventions are associated with the results, it has not yet been possible to identify which specific causal mechanisms are involved in the improvements. Consequently, the preliminary nature of these studies requires that their results be considered with caution while awaiting the replication or accumulation of more evidence on these types of studies. Currently, the importance of this preliminary evidence is that it is possible to support the hypothesis -already raised in interventions with samples of children with developmental disorders- that the efficiency of different neural systems can be modified by specific interventions; and that it is possible that this changes occur beyond the first two or three years of life.

Implications of the evidence, future directions, and contributions of this volume

The available neuroscientific evidence suggests that exposure to poverty is associated with structural and functional modifications of the nervous system, which in turn can be associated with lower performances on tasks with emotional, cognitive, language, and learning demands. Such associations can be mediated or moderated by different individual and contextual factors, among which individual susceptibility, the quality of parenting and educational experiences, as well as exposure to stressful negative events are among the most frequent. Finally, evidence has also begun to accumulate that suggests that such associations can be modified by interventions aimed at training cognitive control (i.e., attention, inhibitory control) and language (i.e., reading) processes, for at least the first decade of life. In summary, the evidence accumulated so far are consistent with the assumptions proposed by the RDS approaches: the associations of poverty with the neural and cognitive systems related to self-regulation and learning would not follow a fixed and immutable pattern due to exposure to deprivation.

This evidence may guide some actions, although not in sufficient detail to suggest specific policy practices in home, educational, or community contexts (Farah, 2018; Lipina, 2016), as can be verified with respect to the contributions in this regard from other disciplines (e.g., National Academies of Sciences, Engineering, and Medicine, 2019). On one hand, the available neuroscientific evidence could eventually complement that generated by other disciplines that address the problem of child poverty and the importance of early development, such as education and developmental psychology. On the other hand, the areas of nutrition, physical activity, sleep, and stress regulation could be those in which to concentrate research efforts to generate interdisciplinary collaborations that may address these issues. These four factors have been shown to be associated with self-regulatory development and learning, and they contribute to the increase or decrease of allostatic load and to learning (Beddington et al., 2008; Ribeiro et al., 2017).

Misconceptions about early critical or sensitive periods for self-regulation and learning, the interruption of development, or the acquisition of irreversible impairments from early exposure to poverty -notions that cannot be sustained with the available neuroscientific evidence- lead to representations of development as a much more fixed and less dynamic phenomenon than the empirical evidence supports. These misconceptions do not adequately consider the levels of plasticity and sensitivity to change in the context of a complex dynamic that involves phenomena not only biological, but also social and cultural.

The available evidence should be incorporated into debates on the contribution of scientific knowledge to social policies aimed at the care of children, adolescents, adults, and the elderly who do not have access to policies that guarantee their rights to health, education, and social development. This necessarily requires that we understand that policy design is a specific area of study of political science. Therefore, it is necessary to incorporate conceptual and methodological discussions in this regard, and this work constitutes a complex process that involves multiple actors and sectors with different interests, tensions, and disputes, which condition at the same time the processes of implementation and evaluation of interventions and policies. In this sense, the available neuroscientific evidence cannot be used to propose normative social objectives of adjustment and mismatch, either fixed or immutable. On the contrary, it contributes to the notion that poverty is associated with loss of rights and competences insofar as the wear and tear of the neural and physiological systems involved reduces opportunities for educational and social inclusion.

In the context of neuroscientific studies on poverty, researchers currently maintain as research objectives: (a) the elucidation of the psychological meaning of structural and functional neural variations; (b) the analysis of such neural differences in a qualitative sense, which contributes to identifying and differentiating adaptation processes (e.g., adaptation versus deficit); (c) the analysis of mediation and moderation dynamics between individual/contextual factors and different aspects of self-regulatory development, which in combination with intervention studies may eventually contribute to the identification of causal mechanisms of the association between poverty and neural development; (d) the identification of opportune moments during neural development to generate actions aimed at optimizing self-regulation development and learning processes; (e) the analysis of mutability and immutability processes by implementation and evaluation of studies with adequately controlled and longitudinal designs for their analysis; and (f) the generation of specific neuroscientific contributions that constitute an added value to that carried out by other disciplines.

Together, these research objectives could eventually contribute valuable evidence for the design and evaluation of specific practices and policies. This requires time, adequate financing –especially in those countries with insufficient resources or economic crises that reduce the possibilities of a continue scientific work, as is currently the case in South America-, and the generation of interdisciplinary and intersectoral collaborations with efficient planning and management. On the other hand, this type of effort necessarily requires the discussion of the implicit representations of human development that each sector supports, which would at the same time allow the updating of ethical, cultural, meta-theoretical, conceptual, and methodological notions, among others, that early childhood efforts today warrant and require.

Some of the aspects that such efforts could consider in the near future are: (a) the identification of specific targets and opportune moments for intervention in the areas of nutrition, physical exercise, sleep, and stress regulation in developmental contexts (i.e., home, school, community); (b) the multilateral financing of research projects aimed at generating large databases based on longitudinal collection of information on populations of interest and that include different levels of organization and developmental contexts; (c) the debate on the cultural relevance of conceptions, models, and designs for evaluation and intervention, in order to avoid or reduce the impact of the replication of standardized formulas in cultures foreign to those of implementation; (d) testing of technologies that permit the acquisition of data on the level of neural organization in developmental contexts (e.g., portable devices for EEG evaluation); and (e) the design of computational methods that include the consideration of information on the development of different levels of organization for the design and evaluation of interventions and policies.

The chapters included in this book provide evidence that raises hypotheses and reflections in line with the main questions in the area of poverty study from a neuroscientific perspective. Both the Rueda and Conejero chapter and the Demir-Lira chapter include initial sections devoted to correlational studies, which expand the available evidence on the associations between early living conditions, cognitive development, and academic performance at both the neural and behavioral levels. In the the Demir-Lira chapter, discussions also involve the importance of considering the opposition between deficit and activation when interpreting the results of neural studies with children living in poverty. The second part of this book includes four chapters that address different questions inherent to intervention efforts aimed at optimizing self-regulatory development and reading at the neural and cognitive level. First, Posner summarizes basic research efforts with animal and human models dedicated to identifying the neural mechanisms involved in intervention change. Pakulak and Stevens share an updated history of the research program carried out during the last decade at the Brain Development Lab of the

University of Oregon, which includes the design, implementation, evaluation, and cultural adaptation of a two-generation intervention. Romeo, Imhof, Bhatia, and Christodoulou update the evidence on an intervention program targeting reading. Such studies also contribute to the debate about the notions of the impacts of poverty as resulting in deficits versus promoting neural adaptation in the face of adversity, suggesting the need to explore variability in response to interventions. Carboni, Delgado, and Nin describe the design, implementation, and evaluation of a cognitive intervention program in the context of the Ceibal Plan in Uruguay. Finally, the third part of the book includes a series of chapters that propose different interdisciplinary explorations to address the analysis of mechanisms that can explain the associations between poverty, adversity, and neural development, as well as the scaling of correlational analysis and identification of mechanisms through different computational tools. These are the chapters of Perry, Thomas, Lomas, and Lopez-Rosenfeld and colleagues, respectively. Finally, Penn offers a series of reflections on the use of neuroscientific evidence in the Early Childhood Development sector, from the critical perspective of contemporary developmental psychology and sociology.

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