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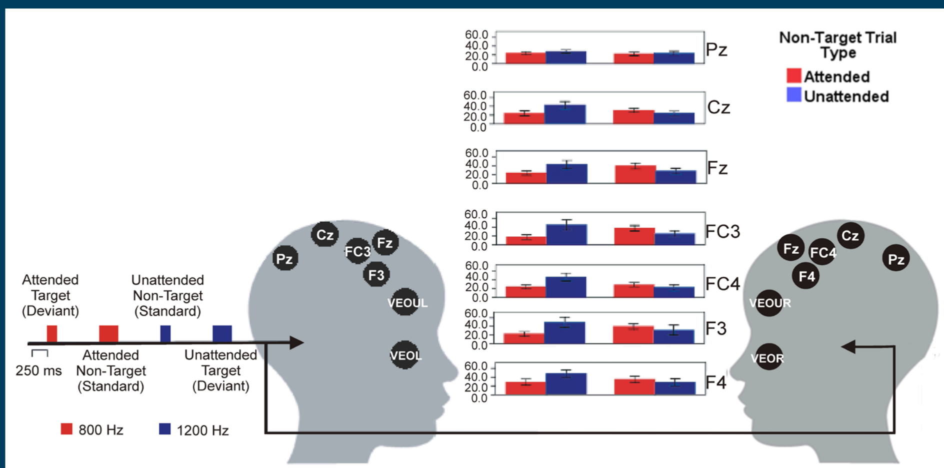

THE SOCIAL EMOTIONAL DEVELOPMENTAL AND COGNITIVE NEUROSCIENCE OF SOCIOECONOMIC GRADIENTS: LABORATORY, POPULATION, CROSS-CULTURAL AND COMMUNITY DEVELOPMENTAL APPROACHES

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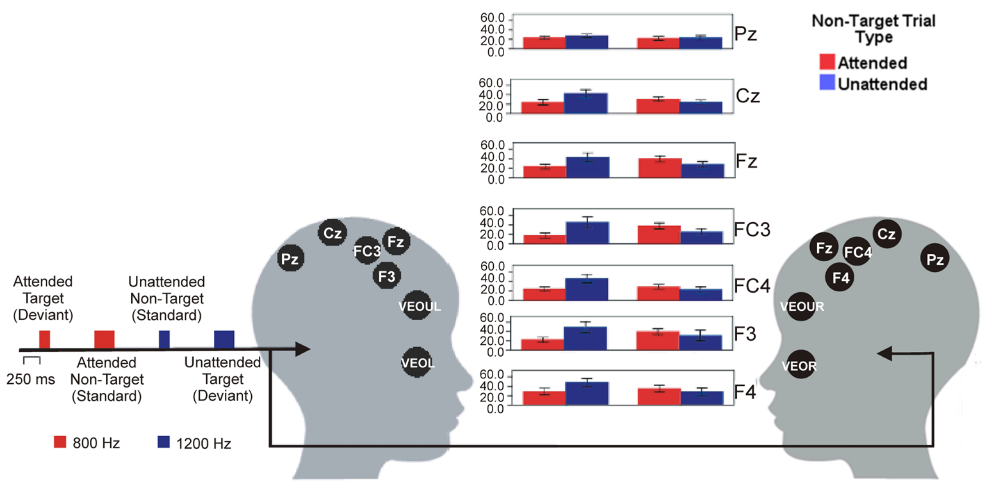

Preadolescent Children's EEG Power responses to attended and unattended distracter tones in an auditory selective attention task
(Details in D'Angiulli, Van Roon, Weinberg, Oberlander, Grunau, Hertzman, et al. (2012a). Frontal EEG/ERP correlates of attentional processes, cortisol and motivational states in adolescents from lower and higher socioeconomic status. Front. Hum. Neurosci. 6:306. doi: 10.3389/fnhum.2012.00306)

The study of the socioeconomic neurogradients—i.e., neural differences corresponding to variations in socioeconomic status (SES)—is a neonate area of transdisciplinary and multidisciplinary research within neuroscience; this Research Topic portrays the current status in addressing social inequities and life-span brain development.

To start off, papers focus on development areas that are commonly known to be influenced by SES, including attention, language and literacy, reading, and numeracy. The life-course maturation and development of brain activation associated with these skills is reviewed by Lipina and Posner (2012), with emphasis on the early years. Although neuroplasticity is present throughout the lifespan, critical periods justify the importance of early intervention. Neuroscientists have the responsibility to recognize the many facets of poverty and to adopt an interdisciplinary perspective when using research to inform public policy and interventions. Furthermore, universal early intervention is recommended—not just targeting lower-SES children.

D'Angiulli et al. (2012a) examine the emotional/motivational states associated with preadolescent children's performance on an auditory selective attention task, which is then correlated with event-related potentials (ERPs) and electroencephalographic (EEG) techniques to identify brain activity associated with levels of SES. Salivary cortisol and affective self-reports were collected throughout the school day. Although lower- and higher-SES children showed similar behavioral performance, the observed patterns of EEG and ERP differences suggest that children from lower-SES may extend more effortful control to perform similarly to their higher-SES counterparts. Lower-SES preadolescents show a genuine (i.e., unconfounded by "non-cognitive" states) information-processing preference to attend equally relevant and irrelevant environmental cues.

To date, neuroscientific research has seldom addressed the relations between SES, cultural factors, and immigrant/native background on children's moral development—the topics investigated by Caravita et al. (2012). These authors find that children from middle-low SES families perceive transgressions of socio-conventional dilemmas (i.e., social order) more strictly than their middle and middle-high SES counterparts, suggesting that environmental circumstances may lead to more rigid guidelines regarding social conventions of morality, because the repercussions may be viewed as more severe (i.e., social exclusion). Incorporating these findings into neuroscientific research would allow better understanding of which brain processes are implicated in moral decision making.

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EDITORIAL
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The social emotional developmental and cognitive neuroscience of socioeconomic gradients: laboratory, population, cross-cultural and community developmental approaches

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Keywords: neurocognitive processes, socioeconomic status, theoretical neuroscience, stress reactivity, cross-cultural differences, cognitive reserve, physical and mental health

The study of the *socioeconomic neurogradients*—i.e., neural differences corresponding to variations in socioeconomic status (*SES*)—is a neonate area of transdisciplinary and multidisciplinary research within neuroscience; this Research Topic portrays the current status in addressing social inequities and life-span brain development.

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In a related domain, Gavrilov et al. (2012) examine young children's social development focusing on the role of joint attention. When offered a toy to engage in play with an adult, children (especially girls) from highly traditional and religious families engage in joint attention more frequently than children from families who are less religious and embrace western standards. In families where gender stereotypes are more apparent, girls appear to absorb these roles and are more in tune with socio-cultural expectations. This may be associated with the earlier maturation of the ventral prefrontal cortex among girls. Joint attention might thus be a mechanism that allows children to appropriate cultural values into behavior with the moderating influence of various bioecological levels.

Examining the concept of ecology further, Hackman et al. (2012) explore whether neighborhood disadvantage influences stress reactivity in adolescents as moderated by gender. African-American adolescents participated in a stress-inducing task as researchers monitored stress reactivity and recovery reflected in salivary cortisol levels. Neighborhood disadvantage was inversely correlated with parental education level. Furthermore, concentrated neighborhood disadvantage was correlated with adolescent stress reactivity and recovery. Particularly, boys demonstrated higher cortisol reactivity and steeper recovery. These findings support firstly the importance of discerning gender effects in adolescent neurogradients and, secondly, considering neighborhood disadvantage as important variable for intervention.

The implications of SES research within neuroscience are reviewed by D'Angiulli et al. (2012b), with focus on poverty. Unidimensional definitions of poverty may fail to capture the complexities of poverty as a multifaceted construct. Alternatively, human-rights based approaches (incorporating ecological measures such as access to education, healthcare, and the work market) may be more representative of the child's contextual and experiential position in society, because these provide a more comprehensive understanding of the children's individual status as opposed to their families. Also critically examined are tendencies for researchers to dichotomize children into extreme groups and make assumptions that lead (implicitly or explicitly) to interpretations that children from lower-SES are inherently deficient (*deficit attribution*).

Collins (2012) describes the necessity of incorporating a child's rights perspective when conducting neuroscientific research with children. The central principles of the United Nations Convention on the Rights of the Child (UNCRC) are reviewed as to how they should inform standards for respectful research with children, these include: non-discrimination, best interests, survival and development, and views of the child/participation. Power differentials can lead to unintentional discriminatory practices when conducting research, as children are often viewed as inferior or in need of "repair." Incorporating a child's rights based-approach forces researchers to critically evaluate how they perceive and treat children, as Collins describes reframing the question of "what is a child?" to "who is a child?"

Calderon-Garciduenas and Torres-Jardon (2012) extend the concept of child's rights by describing the effects of air pollution in Mexico City on brain development. Children severely exposed to air pollution in South Mexico City demonstrated several cognitive deficits, with 56% exhibiting prefrontal white matter MRI hyperintensities. Furthermore, exposed children's autopsies demonstrated that nearly half showed precursors of Alzheimer's disease. However, clearly not all children exposed are at risk of developing neurodegenerative diseases. The role of compensatory mechanisms is described in relation to the many factors impacting children's ability to overcome the effects associated with incremental air pollution exposure. Finally, air pollution exposure is linked with SES, since, lacking the support required for healthy development, low-SES children live in the most hazardous conditions.

Bezo et al. (2012) examine SES and health at the national level, specifically, comparing the relationship between social factors in countries and their impact on physical and mental population health. Through sophisticated statistical modeling, the authors discovered a mediational pathway such that rights and freedoms influenced social capital and SES, leading to improvements in physical and mental health. Namely, in democratic countries where there is more freedom to influence public policy, with governments that are more transparent and less corrupted, citizens feel a sense of trust leading to improvements in SES and health. These findings directly affect life outcomes for children and confirm that higher GDP does not necessarily equate better health, as the link between SES and health is not supported without the mediating effects of rights and freedoms.

Lastly, this Research Topic involves two articles targeting changes over the lifespan. Noble et al. (2012) incorporate a cross-sectional correlational study investigating the association between education and hippocampal and amygdala volume over the lifespan. They obtained data from a standardized database detailing the performance on a memory task along with MRI scans of individuals aged 7–87 years, and discovered that age-related decrease in hippocampal volume is more pronounced amongst individuals with little educational attainment especially after 35 years of age. Such discovery interlocks with the paper that follows.

Using a spatial version of the Stroop task to assess and compare conflict monitoring in older and younger adults, Puccioni and Vallesi (2012) test whether there is an age-related deficit in spatial conflict monitoring independent of priming effects, and whether such deficit in turn is influenced by intelligence, cognitive reserve, and years of education. Although older adults are slower at responding than younger adults on the spatial Stroop task, their accuracy is comparable. This finding supports the theory of a general slowing down effect of aging. Older adults' demonstrate increased difficulty responding to incongruent trials following congruent ones, however, this effect diminishes when higher cognitive reserve exists, suggesting that naturally occurring age-related deficits in attention can be mitigated by rich everyday life experiences.

The variety of articles in this Research Topic truly provide the full spectrum of views on the study of socioeconomic neurogradients today, representing, we believe, comparatively the best examples of research in this field from the full spectrum of methodological and theoretical perspectives.

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The impact of poverty on the development of brain networks

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Although the study of brain development in non-human animals is an old one, recent imaging methods have allowed non-invasive studies of the gray and white matter of the human brain over the lifespan. Classic animal studies show clearly that impoverished environments reduce cortical gray matter in relation to complex environments and cognitive and imaging studies in humans suggest which networks may be most influenced by poverty. Studies have been clear in showing the plasticity of many brain systems, but whether sensitivity to learning differs over the lifespan and for which networks is still unclear. A major task for current research is a successful integration of these methods to understand how development and learning shape the neural networks underlying achievements in literacy, numeracy, and attention. This paper seeks to foster further integration by reviewing the current state of knowledge relating brain changes to behavior and indicating possible future directions.

Keywords: childhood poverty, brain networks, plasticity, attention, literacy, numeracy

INTRODUCTION

The study of the influence of material and social deprivation on the central nervous system (CNS) has been an issue of interest in the agenda of neuroscience since the first half of the twentieth century. Early neuroscience studies analyzed how the exposure to complex, standard, or deprived environments modifies the brain of experimental animals (Hebb, 1949; Mohammed et al., 2002; Grossman et al., 2003; Markham and Greenough, 2004; Sale et al., 2008).

The development of neuroimaging has provided non-invasive methods for examining changes in gray and white matter of the human brain (Posner and Raichle, 1994; Raichle, 2009) and may now serve to better integrate animal work with the century long efforts to specify lifespan changes in critical areas of development. Applying neuroscience methods to issues of child poverty has emerged from these developmental efforts (Hackman and Farah, 2009; Lipina and Colombo, 2009; Hackman et al., 2010). Since the mid 1990s different researchers have used behavioral and imaging to compare the cognitive and academic performance of children with disparate socioeconomic status (SES; e.g., Korenman et al., 1995; Guo, 1998; Lipina et al., 2004, 2005; Mezzacappa, 2004; Noble et al., 2005; Farah et al., 2006). Advances in neuroimaging have made it possible to incorporate neural network analysis in studies of the influence of poverty (e.g., Noble et al., 2007; D'Angiulli et al., 2008; Raizada et al., 2008; Stevens et al., 2008, 2009; Kishiyama et al., 2009).

A major achievement in the use of fMRI to study human development has arisen through the study of brain connectivity at rest (Fair et al., 2009, 2011; Gao et al., 2009). The results to date have shown evidence of sparse connectivity between brain structures during infancy and a strong increase in long range connectivity at 2 years (Gao et al., 2009) and later (Fair et al., 2007, 2009). In studies of neonates, the parietal areas, prominent in the orienting of attention network, show strong connectivity to lateral and medial frontal areas. The mid frontal cortical area and the anterior cingulate cortex (ACC), which have been implicated in self-regulation (Posner and Rothbart, 2007b) and down-regulation of the amygdala during the processing of threatening social cues (McEwen and Gianaros, 2010), show a marked increased connections to frontal areas and to lateral parietal areas during childhood. In older children (Fair et al., 2009), these tendencies continue and the ACC becomes increasingly differentiated from the orienting network as one approaches adulthood. One view of control systems was suggested recently by Fair et al. (2011). They argued, "data suggested that there might be at least two control networks functioning in parallel. Based on the differences in their functional connectivity and activation profiles we suggested that each network likely exerts distinct types of control on differing temporal scales. The fronto-parietal network was proposed to be important for rapidly adaptive control and to work on a shorter timescale. The cingulo-opercular network was thought to be important for more stable set-maintenance, and to operate on a longer timescale. Since this initial work there have now been several reports supporting this framework."

In the present paper, we specifically focus on the issue of neuroscience approaches to childhood poverty using the recent data on brain networks including the resting state data. The resting state studies provide a unique perspective on the developing human brain, but their weakness is the limited evidence on how these changes influence infant and child behavior. In the section of this paper on attention and self-regulation, we try to establish such links, trying to highlight what should be taken in consideration regarding plasticity sensitivity to learning in the first stages of development. The aim of our effort is to review current progress and identify target areas, which could help form a research agenda for the coming years. To carry this out we first examine the general plasticity of the nervous system from the cognitive neuroscience viewpoint. Then we consider in turn the neural networks underlying the regulation of stress, attention and self-regulation, literacy, and numeracy. These topics were chosen because of their importance in normal development and according to one recent review on the mechanisms of executive function and language as the most influenced by SES (Hackman and Farah, 2009; Lipina and Colombo, 2009; Hackman et al., 2010; Raizada and Kishiyama, 2010). We consider the integration of animal and human studies, imaging of both gray and white matter, and the role of genes and specific experience in developing brain networks. We concentrate on linking neuroscience methods with behavioral and psychological approaches to development. In the next to last section we review a number of other current approaches to these same issues. Since there is much we still do not know, in the final section we propose priorities for a research agenda to allow for further progress.

BRAIN PLASTICITY

In recent years, neuroscience has begun to take seriously that experience shapes the brain in important ways. Plasticity has been used as a blanket term to cover these changes. One area of plasticity related to the possible consequences of poverty is that experimental studies on rodents and non-human primates exposed to motor, sensory, and social stimulation, show structural and functional changes in neuronal and non-neuronal components, in comparison with those subjects exposed to deprived environments (see a comprehensive approach to brain plasticity in Rosenzweig, 2003; Markham and Greenough, 2004; Sale et al., 2008; Lipina and Colombo, 2009). These changes include synaptic number and morphology, dendritic arborization, cell morphology, the number of astrocytes and glial-synaptic contacts, myelination, glial cell morphology; brain vasculature; brain cortex weight and thickness, rate of hippocampal neurogenesis, availability and metabolism of both neurotrophic factors and neurotransmitters in different brain areas, and neurotrophic and neurotransmitter gene expression as well.

Complex environments induce neuroanatomical and biochemical changes in several brain areas of young and adult rodents, including frontal, parietal, and entorhinal cortices, hippocampus, and cerebellum (Rosenzweig and Bennet, 1996; Mohammed et al., 2002; Grossman et al., 2003). A considerable body of literature links the hippocampus to various plasticity factors, and to learning and memory mechanisms, such as gene expression and protein levels of neurotrophins, glucocorticoid receptors, the Alzheimer amyloid precursor protein, immediate early genes, serotonin receptors, α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid (AMPA) receptor binding, and neurogenesis (Mohammed et al., 2002). Middle-aged rats that had at least 1 year in complex environmental conditions showed higher levels of nerve growth factor (NGF) in the entorhinal cortex, compared to isolated animals (Mohammed et al., 2002). Furthermore, several studies suggest an involvement of these neurotrophins in the synaptic plasticity of the hippocampus and other brain areas (McAllister et al., 1995). Several neurotrophic factors, such as the NGF, the brain-derived neurotrophic factor (BDNF), and the neurotrophin-3 (NT-3), are abundantly expressed in pyramidal cells and dentate granule cells, a fact suggesting that neurotrophins are involved in mediating changes in the dendritic morphology following exposure to complex environments. In this regard, the role of the hippocampus in learning and memory has been the focus of increased research interest involving the generation of new neurons. Using the proliferation marker bromodeoxyuridine (BrdU), different studies showed that enrichment increases neurogenesis in the dentate gyrus of adult mice and rats. This effect has been associated with learning (Shors et al., 2001), while stress experience has been related to the reduction of neurogenesis (Gould et al., 1997).

The cerebellum has also been found to display plastic properties in response to environmental influences. Specifically, learning of a complex motor skill leads to an increase in the synaptic numbers of the cerebellar cortex, and to changes in the morphology of cerebellar Purkinje cells in rodents and monkeys (Kleim et al., 2003).

Behavioral changes following exposure to enriched environmental conditions are not limited to the improvement of cognitive performance. One robust observation has been based on the effects of isolation. Rodents after being reared in isolated environments interacted less with objects in a free exploration situation, while displaying at the same time an increased locomotor activity coupled to a reduced habituation. These findings would suggest that, depending on the complexity of environmental enrichment or deprivation, brain circuits would be affected with more, or less, specificity involving different cortical areas and subcortical structures. Although the experimental conditions of enrichment/deprivation cannot be identified directly with human poverty they may illuminate some aspects of child poverty (Lipina et al., 2011).

The findings of effects from enriched environments make useful interdisciplinary efforts and in particular to the translational animal and human research. For instance, in the context of analysis of the neural reactivity to stress the study of failures to habituate to repetition of the same stressor or to terminate adaptive autonomic and neuroendocrine response, are based upon the experimental animal–human translational efforts (McEwen and Gianaros, 2010).

Neural plasticity in humans may also lead to structural adaptation in cortical gray matter, in response to environmental demands (Bavelier and Neville, 2002). At the level of imaging studies, there is evidence that the brain may adapt dynamically to reflect environmental cognitive demands. Neuroimaging studies show evidence of structural changes in specific areas after training in difficult motor tasks. For example, studies of professional musicians (Gaser and Schlaug, 2003; Imfeld et al., 2009) show increased size of relevant motor areas, and selective increases in gray matter volume in posterior hippocampus. In addition, concomitant spatial memory performances have been shown in licensed London taxi drivers (Woollett and Maguire, 2011).

Current studies in the developmental neuroscience field continue to advance in the understanding of the plastic mechanisms through which experience and environmental influences interact with genes, more specifically with the DNA biochemical markers and histone proteins that regulate gene activity. Specifically, post-translational modifications of histones and DNA methylation are the most frequently analyzed mechanisms, involved in changes in gene activity with environmental factors (Zhang and Meaney, 2010; Roth and Sweatt, 2011). Learning and memory processes also evoke alteration of epigenetic markers in the adult CNS, as shown by animal models. For instance, Miller and Sweatt (2007) have used the contextual-fear conditioning paradigm to analyze epigenetic modulation of hippocampal genes. They found that during a period of fear memory formation, adult rats have a demethylation and transcriptional activation of the memory-enhancing gene reelin, and an increase in methylation and transcriptional silencing of the memory suppressor gene protein phosphatase 1.

These multiple changes in neural structure are correlated with functional changes in motor, cognitive, and emotional systems and behaviors (Mohammed et al., 2002; Grossman et al., 2003; Markham and Greenough, 2004). Thus, development and learning alter the local neural environment and that lead to the observed changes in brain and behavior (Galván, 2010).

For humans poverty is associated with a restricted environment and thus it would be expected that SES would be correlated with differences in brain and behavior. Researchers have reported that the modulation of performance by SES is not the same in all areas of behavior nor uniform at all ages (e.g., Lipina et al., 2004; Noble et al., 2005; Farah et al., 2006). Actually, SES is a multifaceted construct hard to capture by single or multifactor indexes, and each component (e.g., income, education, and occupation) represents resources that might benefit development in different ways (Duncan and Magnuson, 2012). Conceptually, this implies that poverty does not necessarily generate homogeneous and continuous changes in neurocognitive processing. These findings move away from the notion of low-SES performance as a deficit. Instead we need to develop measures for different brain networks; ages and SES/poverty conditions to contribute understand how poverty and SES shape brain networks development. For instance, Evans et al. (2005) have pointed to the role of chaotic unpredictable family environments – a specific aspect of SES, which is usually not analyzed – as a threat to emotion regulation. With the complexities of SES in mind developmental cognitive neuroscience may serve as fertile ground for new ideas about the role of SES in development.

In summary, the findings from behavioral studies indicate that SES disparities and poverty can adversely affect cognitive processes, such as language, executive function, attention, and memory. In addition, these findings suggest that specific brain regions are associated with these cognitive functions. However, these tests are still behavioral in nature and as such, they are subject to a number of limitations. For instance, researchers can make only indirect inferences about brain function from behavioral tests. In addition, many of these tests are multifactorial and performance could be disrupted for reasons other than those resulting from a specific dysfunction. Moreover, correlations among these tests are low, which means that two tasks can engage the same system in different ways. So a deeper examination of the impact of SES and poverty on the relationship between cognitive processes and brain function is needed. To this end, neuroimaging techniques can be applied to analyze the neural level of analysis.

BRAIN PLASTICITY AND STRESS

The stress system has been used as a model system for an examination of adverse early experience on a brain network (see Lupien et al., 2009 for a review). The basic brain network involved in the stress response is the hypothalamus–pituitary–adrenal (HPA) axis. It is vertically organized and involves the autonomic and the CNSs and hormonal as well as neural function.

Stress-related studies have been carried out in a variety of non-human animals as well as in humans (Lupien et al., 2009). These studies rely heavily on animal models to examine the effects of early environmental effects such as maternal care, caregiver maltreatment, mother–infant separation, and prenatal stress. The evidence suggests that early stress can produce lasting epigenetic modifications, stable changes in the CNS gene activity, as well as on behavior. For example, adult offspring raised by mothers providing high level of pup licking and grooming showed molecular changes in hippocampal glucocorticoid receptors, transcription of neural growth factor, corticotrophin releasing factor expressions, and glucocorticoid feedback sensitivity (Zhang and Meaney, 2010; Roth and Sweatt, 2011). Human studies by Roth et al. (2009) suggest that caregiver maltreatment can result in modified methylation of the BDNF in the prefrontal cortex, and a DNA hypermethylation, which paralleled a lasting deficit in expression of the gene. These effects could be treated in part by a DNA methylation inhibitor administered to adults. Similar findings in animal models resulted from maternal separation (Zhang and Meaney, 2010).

The epigenetic analysis of the early experiences on brain development in humans is in its first stages as many of the issues in the study of childhood poverty and brain development. For instance, recently McGowan et al. (2009) examined the gene expression and DNA methylation of the human glucocorticoid receptor (Nr3c1) gene in hippocampal samples from suicide victims with a history of childhood maltreatment. They found decreases levels of mRNA hippocampal glucocorticoid receptor gene, correlated with increases of cytosine methylation of the Nr3c1 promoter, which suggests that human caregiver experiences may program genes through epigenetic modifications. Bueller et al. (2006) have found evidences that carriers of the methionine allele of the Val66Met BDNF polymorphism express lower gray matter volume in the hippocampus and prefrontal cortex compared with carriers of the valine–valine allele, suggesting a pathway of modulation of BDNF secretion and intracellular functioning. In another study, Oberlander et al. (2008) found that infants of mothers with high levels of depression and anxiety during the third trimester of pregnancy had increased methylation of the Nr3c1 gene promoter in cord blood cells.

These studies support the hypothesis that the epigenome of prenatal developing infants is sensitive to the experiences of their mothers. Of course, many methodological issues should be explored in future studies, such as whether peripheral measures of DNA methylation accurately reflect CNS methylation (Roth and Sweatt, 2011).

In summary, we stress two important points from the work on stress. First it shows the importance of a distributed systems of brain areas in the control of stress, involving prefrontal cortex, hippocampus, amygdala, and the HPA axis (Lupien et al., 2009) which operate as a non-linear, interactive network in which multiple mediators regulate each other, and promote adaptive activities and coping with aversive situations and discrete stimuli, such as those usually present in low-SES and poverty contexts (e.g., crowding, hunger, threats to mental and physical health). These areas and the white matter connection between them are important contributors to the influence of stress on the person. Experimental animal models of the hippocampus have revealed a mechanism by which chronic stress leads to remodeling of hippocampus circuitry. These changes consist in shortening of dendrites, loss of spine synapses, and suppression of neurogenesis in the dentate gyrus. One of the effects of these processes is impairing hippocampal involvement in episodic, declarative, contextual, and spatial memory, what in turn leads to alter the ability to process information in new situations and to make decisions about how to cope with new challenges (McEwen and Gianaros, 2010).

Second, is the notion that epigenetic changes underlie the long-term impact of early experiences, and that epigenetic alterations are potentially reversible or modifiable through pharmacological and behavioral interventions. This means that the understanding of the role of genes and of the epigenome in behavioral modifications driven by early experiences could contribute to the field of childhood poverty and brain development. However, the presence of genetic variation in humans suggests that similar childhood experiences could produce different outcomes depending upon the exact version of the gene present in the individual. A child's reaction to stress is an important factor in success in school and our understanding of the stress reaction may also guide us in analyzing other brain systems more directly involved in schooling as we try to do in the remaining sections of this paper.

ATTENTION

Attention is a key factor in school readiness and success (Posner and Rothbart, 2007a). An understanding of the underlying brain networks involved in attention has been a major contribution from research using neuroimaging (Posner and Petersen, 1990; Posner and Rothbart, 2007b; Petersen and Posner, 2012). Attention networks are involved in obtaining and maintaining the alert state (alerting network), orienting to sensory stimuli (orienting network), and resolving conflict between responses (executive network). The executive network is a key to the role of ability of children and adults to regulate their thoughts and feelings. Adjacent areas of the ACC are involved in cognitive and emotional control (Bush et al., 2000). Connectivity of these control systems develop over the early life of infants and young children, and lead to the ability to regulate other brain networks, thus exercising executive control over behavior (Fair et al., 2007, 2009, 2011; Gao et al., 2009; Posner et al., 2012). This control depends critically upon factors in the social environment such as parenting. Better understanding of the mechanisms by which control develops and is exercised can provide guidance to parents and to society. Critical to this is an understanding of the mechanisms, which switch control from the caregiver during infancy to later self-regulation by the child.

One function that has been traced to the frontal midline (ACC) is monitoring and correction of errors. The ability to notice perceptual errors occurs as early as 7 months (Wynn, 1992; Berger et al., 2006) and activates the anterior cingulate in infants just as it does in adults. However, infants of this age are not able to use the information to control their behavior. We had children play a simple Simon game that asked them to execute a response command given by one puppet while inhibiting commands given by a second puppet (Jones et al., 2003). Children of 36–38 months showed no ability to inhibit their response and no slowing following an error, but at 39–41 months children showed both an ability to inhibit and slowing of reaction time following an error. These results suggest that between 38 and 39 months, performance changes based upon detecting an error response. These dramatic changes in error correction relate to the changing connectivity of the brain during early child development, as was indicated by studies with neonates and older children in which parietal areas related to orienting of attention show strong connectivity to lateral and medial frontal areas, and the ACC shows increased connections to frontal areas and to lateral parietal areas (Fair et al., 2009), suggesting tendencies of increasing differentiation in the networks involving parietal and frontal areas related to attentional processing.

However, changes in brain connectivity are not finished at age 3. The Attention Network Test (ANT) has been used to examine the efficiency of the three brain networks (Fan et al., 2002) in older children and adults. The task requires the person to press one key if the central arrow points to the left and another if it points to the right. Conflict is introduced by having flankers surrounding the target point in either point the same (congruent) or opposite (incongruent) direction as the target. Cues presented prior to the target provide information on where or when the target will occur. Reaction times for the separate conditions are subtracted, providing three measures that represent the efficiency of the individual in alerting, orienting, and executive networks.

We have examined the ANT in children from 6 to 10 years of age using a version specifically adapted to them. The results for children of this age are similar to those found for adults using the same child version of the task. The child reaction times are much longer, but they show similar independence between the three networks. Children have larger scores than adults for alerting up to age 10 and for conflict up to age 7, suggesting that young children have trouble in resolving conflict and even older children have trouble in maintaining the alert state when not warned of the target (Rueda et al., 2004).

SES EFFECTS ON ATTENTION NETWORKS

In studies of preschoolers, first graders, and middle school children, low-SES children had reduced performance on many tasks compared to middle SES children (Noble et al., 2005; Farah et al., 2006). These findings suggest that the prefrontal/executive system is one of the primary neurocognitive systems associated with social inequalities in early experience. Similar results have been observed in studies using specific paradigms designed to measure aspects of both executive function and attention. For example, Lipina et al. (2005) examined performance of low and middle SES infants using a task of a delayed-response paradigm, which incorporates the evaluation of processes such as working memory and inhibitory control. Findings showed that low-SES infants made more errors associated with impairments of inhibitory control and spatial working memory, and errors associated with attention and search strategies.

The effects of socioeconomic disparities on attention have been examined in several studies. For instance, Mezzacappa (2004) used the ANT to investigate the effects of socioeconomic disparity on attentional processes in children of 6 years of age. This task can be used to assess alerting, orienting, and executive attention networks. Results showed that low-SES children had reduced measures of both speed and accuracy on measures of alerting and executive attention, indicating that SES modulated response conflict and inhibit distracting information.

Another report on the difficulty low-SES children have in attention comes from studies comparing the performance of high and low-SES children attempting to listen to a story presented to one ear while ignoring that on another ear. Performance is assessed by the amplitude of the P1 component of the auditory event-related potential (ERP) known to be influenced by attention. Low-SES children show little evidence of attention amplifying this EEG component while higher SES children of the same age show clear evidence of P1 amplification for the attended ear. After a period of training in classroom that provided practice in various attention networks the SES children also showed the influence of attention on P1 (Stevens et al., 2009; Neville et al., 2011).

FORMS OF ATTENTION TRAINING

There has been considerable evidence that various types of attention training can be effective in children (Rueda et al., 2005, 2012; Diamond et al., 2007; Tang and Posner, 2009; Diamond and Lee, 2011; Neville et al., 2011; Klingberg, 2012; Segretin et al., 2012). Most of the evidence involves practice with attention related tasks either using computerized tasks or classroom curricula. Although it is likely that many of these methods target executive attention network, some may train primarily orienting to sensory stimuli. These methods have been shown to be effective in normal preschool children and in children with disorders such as ADHD or those with low-SES. It is not possible to say which methods are most effective. The computerized methods allow rather compete specification of the training, while the classroom methods provide more practical means of training. Most of the studies have not examined how long the training is effective, but one study suggested little loss after 2 months (Rueda et al., 2012). In general, many studies of early preschool education have shown that the advantages for specific skills taught in school disappear in a few years, but there is some evidence that general benefits of training of executive skills last for many years (Moffitt et al., 2011).

A second type of training involves changes in brain state that might influence some attentional networks as well as stress and immunoreactivity. For example, physical exercise has been shown to have general advantages for improving cognitive function in adults and elderly (Hillman et al., 2008) and meditation has been shown to have a specific influence on executive attention and stress in undergraduates (Tang et al., 2007). Meditation has been shown to be effective in children as young as 4 years of age (Tang et al., 2012), but the role of this method with low-SES children remains to be demonstrated.

LANGUAGE AND LITERACY

Language and literacy are important in school and are functions found to be reduced in low-SES children. According to a recent analysis (Hackman et al., 2010) one of the systems most at risk for low-SES children involves language. In recent years, the way in which experience shapes language development starting in infancy has been analyzed in detail. Below we review some of these findings.

In the 1970s, behavioral studies using habituation to a repeated stimulus provided evidence that from birth infants are able to discriminate basic phonemes, the basic constituents of language, not only in their own language but also in other languages to which they have never been exposed (Eimas et al., 1971; Streeter, 1976). Studies using these behavioral methods together with electrical recording from the scalp have probed some of the early development of the phonemic structure underlying language. More recently, infants have been exposed to language while resting in fMRI scanners to examine the brain mechanisms activated by language (Dehaene-Lambertz et al., 2006).

The infant language system appears to involve the same left hemisphere language structures found in adults (Dehaene-Lambertz et al., 2006). In one study infants listened to sentences presented aurally in their language. Brain areas in the superior temporal lobe (Wernicke's area) and in Broca's area were active. When the same sentence was presented after a delay of 14 s Broca's area activity increased, as though this area was involved in the memory trace.

It has long been supposed that the early acquisition of language might involve very different mechanisms than are active in adults (Vicari et al., 2000). Left hemisphere lesions in infancy do not produce a permanent loss of language function as they can in adults. Nonetheless, the new fMRI data suggests the left hemisphere speech areas are involved in receptive language even at 3 months of age and even though brain damage at this early age may allow the same functions to develop in the right hemisphere (Dehaene-Lambertz et al., 2006).

PHONEMES

It has been possible to study changes in phonemic discrimination due to exposure to the native language at least by 10 months of age (Kuhl, 1994; Saffran, 2002). Infants appear to acquire a sharpened representation of the native phonemic distinctions (Kuhl et al., 2006). During this same period, they also lose the ability to distinguish representations not made in their own language (Werker et al., 1981). At least a part of the loss occurs when the non-native language requires a distinction that is within a single phonemic category in the native language. An example is the *ra–la* distinction important in English is lost because it is within a single category in Japanese (McClelland et al., 2002). It is as thought Japanese no longer hear this distinction and even when exposed to English they may not improve in distinguishing *ra* from *la*. In the McClelland et al.'s (2002) study an adaptive training regime starting with initially easy stimuli was contrasted with a fixed training regime using difficult stimuli, with some subjects receiving feedback on the correctness of their responses and others receiving no feedback in both conditions. After three and six sessions of training, subjects received tests assessing identification and discrimination of /r/–/l/ stimuli as well as generalization. In all cases except fixed training without feedback, subjects showed clear evidence of learning, and several indicators suggested that training affects speech perception, rather than simply auditory processes. Thus, training by several methods (McClelland et al., 2002; Iverson et al., 2005) seems to improve this form of phoneme discrimination even in adults, although it is not known how well this knowledge can be incorporated into normal daily life communication.

It might be useful to find a way that will preserve the distinctions originally made for the non-native language during infancy. One study showed that 12 sessions of exposure to a mandarin speaker during the first year of life help to preserve a mandarin phoneme in children whose native language was English (Kuhl et al., 2003). A similar amount of exposure to a computerized version of the speaker was not effective, suggesting the importance of social interaction in this early form of learning. More needs to be learned about how and whether media presentation can be effective in learning.

There are many reasons why it is useful to know more than one language. Much of the world population lives in places where speakers of two or more language live in close proximity. In addition, there is some reason to believe that proficiency in a second language provides improved performance in the ability to exercise executive control over thoughts (Bialystok and Martin, 2004), which might be one form of attention training.

There is also some reason to believe that the process of phonemic discrimination being developed in infancy is important for later efficient use of spoken and written language (Molfese, 2000; Guttorm et al., 2005), which is critical in childhood poverty studies since SES modulates the early language environments (Hoff, 2003). Electrical recording taken in infancy during the course of phonemic distinctions (Molfese, 2000; Guttorm et al., 2005) have been useful in predicting later difficulties in language and reading. There is a history of using ERPs to assess infant deafness early in life and being able to do so reliably have been very useful in the development of sign language and other interventions to hasten the infant's ability at communication. Perhaps a similar role will prove to be possible for ERPs in the development of methods to insure a successful phonemic structure in the native language.

There have been efforts to develop appropriate intervention in later childhood for difficulties in the use of language and reading such as the widely used *FastForward* programs (Temple et al., 2003). Although there are disputes about exactly why and for what populations this method works it remains important to develop remedies for language difficulties based upon research.

READING

Reading is a high-level skill and in alphabetic languages such as English, it has properties related to the phonemic structure of language. There have been many studies of adult reading and much more is known than can be reviewed here (see Posner and Rothbart, 2007a; Schlaggar and McCandliss, 2007 for reviews). Adult studies of reading have revealed a complex neural network involved in the translation of words into meaning. Two important nodes of this network are the visual word form area, of the left fusiform gyrus and an area of the left temporal–parietal junction for translating visual letters into sounds. The activation of the left temporal–parietal junction is modulated by SES, among other factors (Monzalvo et al., 2012).

Languages like English that are highly irregular in visual to sound mappings are heavily dependent upon brain areas that translate visual words to sound. Children who have difficulty in learning to read show little activation in these phonological areas (Shaywitz et al., 2007). Many of the studies of learning to read use dyslexic children who have shown specific difficulties in learning to read, some of what has been learned probably will apply to low-SES children as well, since the child's ability in phonemic awareness, (e.g., rhyming of auditory words), is a good predictor of their being able to learn to read alphabetic languages such as English. Training studies designed to improve decoding have shown that children with low reading skill can improve and when this occurs they show enhanced activation in areas related to phonological translation (McCandliss et al., 2003a,b).

The visual word form area is involved in integrating or chunking visual letters into words (McCandliss et al., 2003b). Although there has been some dispute about its unique operations it appears to be a part of the visual system that becomes expert in dealing with letters as reading skill develops in later childhood (Price and Devlin, 2004; Ben-Shachar et al., 2011). It is thought that without the functioning of this area reading cannot become fluent. For example, patients with a lesion that interrupted the flow of information from the right hemisphere to the visual word form area used letter by letter reading when words were presented left of fixation (going to the right hemisphere), while they read words normally when the word was projected to the left hemisphere and thus reached the visual word form area (Cohen et al., 2004). Children from 7 to 18 who were deficient in both decoding and comprehension skills failed to activate this area, but were able to do so after extensive phonological training (Shaywitz et al., 2007).

The time course of development of the visual word form area in English is important for the development of fluent reading. Phonics training often leaves the child with improved decoding skill, but with a lack of fluency. Evidence that the visual word form develops rather late and first only for words with which the child is familiar (Posner and McCandliss, 1999), suggests the importance of continuous practice in reading to develop fluency (Shaywitz et al., 2007). More research is needed on the best methods for developing fluency particularly in non-alphabetic languages.

LOW-SES CHILDREN LEARNING TO READ

A study by Noble et al. (2007), hypothesized that SES systematically influenced the relationship between phonological awareness skills and brain activity in areas involved in reading. Phonological awareness, as we discussed in the Section "Phonemes" has been a key predictor for success in learning to read. To test this hypothesis, researchers examined fMRI responses during a pseudoword reading task in first- to third-graders from diverse SES backgrounds. Results showed a significant phonological awareness–SES interaction in the left fusiform visual word form area, indicating that at similar low phonological awareness levels, children from higher SES were more likely to evidence increased responses in the left fusiform cortical gyrus, while children from lower SES did not.

In another recent study of healthy 5-year-old children performing an auditory rhyme-judgment task, Raizada et al. (2008) found a more direct relation: the higher the socioeconomic status, the greater the degree of hemispheric specialization in Broca's area, as measured by the left-minus-right fMRI activation during rhyming tasks. This suggests that the maturation of Broca's area in children may be governed by the complexity of the linguistic environments in which they grow up.

SUMMARY

Language development begins very early in infancy. Exposure to language shapes the phonemic structure in a way, which could influence later acquisition of literacy. Imaging studies have traced the brain structure and connectivity involved in learning language and acquiring literacy. Interventions for improving brain areas in children with low learning skill have been developed and proven useful both for decoding of letters into their auditory form and for chunking letters into a visual unit. It seems likely that children in poverty face difficulty in all of these operations. Their exposure to reduced input of language during infancy may cause problems with perceiving phonemes, which in turn predicts performance in acquiring reading. Future studies may lead to further development of interventions designed to improve these skills in all children.

NUMERACY

The human infant like other animals seems to have an inborn skill to recognize quantity. At least by a few months of age the infant seems to be able to discriminate changes when presented with a small number of events presented. Wynn (1992) showed that infants of 7–9 months looked longer when simple addition problems (presented as puppets) were in error than when they were correct. Berger et al. (2006) compared this ability in 7- to 9-month-old children and adults, using high-density electrical recording from the scalp. They found the same electrodes over frontal midline areas discriminated between errors and correct in both infants and adults. The adult brain made the discrimination by about 250 ms and the infant brain was only delayed by about 50 ms. The authors showed that error detection was signaled by an increase in theta rhythm in both groups. The electrodes in question had been related to activity in the dorsal ACC in previous studies (Dehaene et al., 1994).

The overall network of brain activity in processing number has been studied in children and adults by high-density electrical recording in a task which required the person to indicate by pressing keys whether a digit was above or below 5 (Dehaene, 1996; Temple and Posner, 1998). Children as young as 5 years of age showed similar brain mechanisms underlie the decision as found in adults suggesting that the number line can be used by this age. There has been some dispute concerning the developmental course of the number line as some studies have suggested frontal structures (Ansari et al., 2005), rather than parietal structures mediate this decision (Cantlon et al., 2006).

Apparently, there are linguistic and cultural differences in the use of Arabic digits in the performance of calculations that could have important consequences for the acquisition of language by children in different parts of the world. Using Arabic digits commonly employed by many cultures, the ability to make simple numerical comparisons were compared for Chinese and English native speakers. Despite the identical input and tasks used, quite different networks of brain areas were used by the two groups. English native speakers used the network of parietal and frontal areas discussed above. However, Chinese natives relied on premotor areas not found active for English speakers (Tang et al., 2006). These fMRI findings indicate the different neural systems may be involved in dealing with very simple numerical tasks. We do not know the reasons for these differences, but if they arise from training, it may provide a way to improve the understanding of quantity, which has shown to be deficient in low-SES preschool children (Griffin et al., 1995).

As the tasks were increased in difficulty by requiring addition as well as comparison the English natives speakers used language areas, as had been reported previously for exact calculation (Dehaene et al., 1999). In addition, English speakers activated limbic areas related to anxiety. However, Chinese native speakers did not show activation of language areas, nor of areas related to anxiety and negative affect. Whether the differences between Chinese speaking and English speaking children lies in genes, early experience, educational method of some other difference is yet to be determined and is of great importance because of the strong advantage which various Asian groups have shown in elementary arithmetic tests. The imaging results show that the brain networks used by Chinese children differ from English speakers suggesting that more than mere effort is involved, but has not yet provided a clear reason for the difference.

INFLUENCE OF SES

There is wide agreement that learning of arithmetic operations depends on the early skill in the ability of children to understand quantity (Siegler, 2009). Significant differences in the numerical proficiency of preschoolers and kindergartners from different SES backgrounds have been described on a wide range of tasks such as reciting the digits, counting sets of objects, counting up or down from a given number other than 1, recognizing written numerals, adding and subtracting, comparing numerical magnitudes, and the ability to describe thinking and explain ideas in the context of mathematical problem solving (Crane, 1996; Pappas et al., 2003; Ramani and Siegler, 2008).

Studies using a program called Rightstart (Griffin et al., 1995) indicated that children from low-SES homes were at high risk for failure in elementary school arithmetic, but training in numerical quantity before the start of school could greatly reduce this deficit. Manual and computerized exercises based on this concept have been developed for young children. For instance, Ramani and Siegler (2008) have tested the prediction that playing linear number board games should enhance children's numerical knowledge by applying an intervention in which low-income preschoolers played a game for 1 h. Results showed increased proficiency on several numerical tasks (i.e., magnitude comparison, number line estimation, counting and identification). They have also verified that these gains remained 9 weeks after playing and that home experience playing number board games were associated with numerical knowledge, suggesting that playing these games with children from low-SES or poor homes would increase their numerical knowledge. In addition, Wilson et al. (2009) tested the effectiveness of an adaptive game designed to improve number sense in a sample of low-SES kindergartners. They have found that children improved their numerical competences in comparison of digits and words suggesting a change only in one aspect of the number sense competences (i.e., access).

SUMMARY

The study of attention, literacy and numeracy all point to common roots of school success in the experiences of infancy (Blair and Razza, 2007). Of course as has always been thought the preschool period is important for preparing the child for a successful school experience. We now have many more studies of how these advances arise in the shaping of brain networks. Explicit or implicit training in attention at preschool level may foster the learning of wide variety of skills acquired in school including literacy and numeracy (Posner and Rothbart, 2007a). Brain-oriented research points to both the specific experiences needed and methods to assay whether they have been achieved, as for example the adaptation of the approaches designed by Ramani and Siegler (2008) and Wilson et al. (2009) for low-SES kindergartners, to the classroom context.

OTHER CURRENT APPROACHES

Several publications reviewing the role of SES and poverty in physical, cognitive, and socioemotional development have been published (Hackman and Farah, 2009; Lipina and Colombo, 2009; Evans and Kim, 2010; Raizada and Kishiyama, 2010). For example, from a developmental cognitive perspective, Bradley and Corwyn (2002) provide an overview of the association between SES and children's well-being in cognitive, socioemotional, and health development domains. In their approach, the cognitive domain was considered in terms of school achievement, language proficiency and IQ; and the socioemotional domain was approached in terms of symptoms of psychiatric disturbance (e.g., internalizing/externalizing behaviors, use of substances) and maladaptive social functioning.

From a combined developmental and sociological perspective, Conger and Donnellan (2007) have addressed the relationship between SES and health disparities, over the life span. They have analyzed three general theoretical approaches aimed at providing explanations for SES and development associations: the social causation, social selection, and interactionist theories. Duncan and Magnuson (2012), based on recent evidence involving associations between manipulation of family income and children cognitive functions (Duncan et al., 2011), have noted the need to increase the sophistication in the measurement and modeling of SES.

From a health perspective, Evans and Kim (2010) have approached the analysis of SES gradients in terms of exposure to multiple risk factors (e.g., low housing and neighborhood quality, pollutants, toxins, crowding, and noise) that vary with SES. Walker et al. (2011) have reviewed the inequality between groups in developing countries that originate in early adverse experiences. They describe the impact of risk factors (e.g., low cognitive stimulation, stunting, iodine and iron deficiencies, intrauterine growth restriction, malaria, lead exposure, HIV infection, maternal depression, institutionalization, exposure to social violence) with the aim of providing priorities for intervention programs and policies. Mathews and Gallo (2011) attempt to revise psychological theories of SES and physical health, by reviewing psychobiological (i.e., biomarkers, neurotransmitters) and psychosocial factors (i.e., stress and distress).

Using an interdisciplinary perspective that integrates economics, neuroscience, and developmental psychology, Heckman (2006, 2008) considers the rates of return to human capital investment for low-SES children. In his framework, skill formation follows a hierarchical order in which later attainments build on earlier foundations, the author argues that developmental disadvantage arises more from lack of early family stimulation than from the lack of financial resources, so late remediation strategies are not effective.

All these approaches point to the following factors as mediators between SES/poverty and socioemotional and cognitive development: nutrition, access to health care, housing, stimulating cognitive materials and experiences, parent expectations and styles, teacher attitudes and expectations, allostatic load (see below), and health-relevant behaviors.

Recent reviews have discussed SES related to neurocognitive differences. For example, Hackman and Farah (2009) and Lipina and Colombo (2009) have reviewed studies in which behavioral, electrophysiological, and neuroimaging methods have been used to characterize SES disparities in neurocognitive functions. Language and cognitive control showed the most sensitivity to SES. Hackman et al. (2010) examined pre- and post-natal levels of stress, the role of parental care in the development of hippocampal structure and function. The epigenetics of regulation of the HPA axis and the capacity of home environment to stimulate cognition are candidate mechanisms by which SES influences brain development.

McEwen and Gianaros (2010) focused their review on the links between stress-related processes in the social environment and the brain (mainly in adults). The authors have illustrated the joint roles of amygdala, hippocampus, and prefrontal cortex as the brain systems mediating allostatic processes.

Finally, Raizada and Kishiyama (2010) have focused their review on the open research opportunities in the area, and the importance of integrating the neuroimaging dimension to behavioral approaches in the study of how SES disparities influences cognitive and socioemotional development, and intervention efforts as well.

FUTURE DIRECTIONS

Biological and psychosocial risk factors associated with low-SES and poverty conditions are related with inequalities in child cognitive and socioemotional development that poses a threat to educational attainment and adult productivity worldwide

(Heckman, 2006; Walker et al., 2011; Marmot et al., 2012). Low-SES and poverty can have profound effects on the brain and body, and thus influence both mental and physical health.

Policies and interventions can affect neuroplasticity. Emerging translational animal and human research link poverty to neurobiological pathways through changes in gray and white matter (McEwen and Gianaros, 2010). We are at the very start of developing interventions that may aid in improving this situation. In the fields of attention, literacy and numeracy we have reviewed interventions using classroom and individual computer exercises that have proven useful in some low-SES and poor populations.

Much remains to be done to establish the efficacy and improve these interventions. Neuroscience studies and intervention need to consider the complexity of SES as the social sciences have proposed (Evans and Kim, 2010; Mathews and Gallo, 2011).

Another issue that neuroscience should take in consideration is a comprehensive approach to development in terms of theories from other disciplines. Recently, Rao et al. (2010) have made such an effort by using a longitudinal data set including ecologically valid in-home measures of early experience during childhood, and structural brain imaging during adolescence, and have found that parental nurturance at age 4 predicted the volume of the left hippocampus in adolescence. In addition, the association between hippocampal volume and parental nurturance disappeared at age 8, suggesting the existence of a sensitive developmental period for brain maturation. Finally, as Crone and Ridderinkhof (2011) have recently addressed "little headway has been made toward understanding how brain growth maps onto mental growth during child development." In their review, these authors have aim at bridging and integrating recent human brain maturation findings with the conceptual thinking of theorist in the behavioral tradition of studying cognitive development. In such a context, developmental research in the area of self-regulation could serve as a reference point for understanding the relation between brain and mental development.

It is our hope that this paper may help to enhance our current knowledge. Research could encourage both parents and those responsible for public education to put more emphasis on preschool and early elementary education and to foster their task of ensuring the educational future of the world's children.

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Explicit and implicit issues in the developmental cognitive neuroscience of social inequality

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The appearance of developmental cognitive neuroscience (DCN) in the socioeconomic status (SES) research arena is hugely transformative, but challenging. We review challenges rooted in the implicit and explicit assumptions informing this newborn field. We provide balanced theoretical alternatives on how hypothesized psychological processes map onto the brain (e.g., problem of localization) and how experimental phenomena at multiple levels of analysis (e.g., behavior, cognition and the brain) could be related. We therefore examine unclear issues regarding the existing perspectives on poverty and their relationships with low SES, the evidence of low-SES adaptive functioning, historical precedents of the "alternate pathways" (neuroplasticity) interpretation of learning disabilities related to low-SES and the notion of deficit, issues of "normativity" and validity in findings of neurocognitive differences between children from different SES, and finally alternative interpretations of the complex relationship between IQ and SES. Particularly, we examine the extent to which the available laboratory results may be interpreted as showing that cognitive performance in low-SES children reflects cognitive and behavioral deficits as a result of growing up in specific environmental or cultural contexts, and how the experimental findings should be interpreted for the design of different types of interventions—particularly those related to educational practices—or translated to the public—especially the media. Although a cautionary tone permeates many studies, still, a potential *deficit attribution*—i.e., low-SES is associated with cognitive and behavioral developmental deficits—seems almost an inevitable implicit issue with ethical implications. Finally, we sketch the agenda for an ecological DCN, suggesting recommendations to advance the field, specifically, to minimize equivocal divulgation and maximize ethically responsible translation.

Keywords: EEG, ERPs, fMRI, neurocognitive processes, neuroimaging, socioeconomic status, theoretical neuroscience

INTRODUCTION

In the domain of developmental cognitive neuroscience (DCN), the study of poverty and social gradients is a very young area of research where a core consensus is quickly emerging from basic results. However, as any emerging scientific discipline, the approaches used are influenced by epistemological stances inherited from other disciplines, and potentially implicit beliefs systems. Explicitly or inadvertently, such influences can lead this critically important new area of research to methodological and ethical foundational challenges. For example, some of the issues in need of debate are: conceptual and operational definition criteria of socioeconomic status (SES) and poverty, scarcity of specificity on how children experience different types of deprivation in different settings, and scarcity of critical cross-cultural considerations regarding social exclusion mechanisms. Debate on these and other issues involves the building of consensus on interventions aiming at attenuating the effects of socioeconomic disadvantage on children's development. Without a critical analysis of the emerging issues, scientists may dangerously risk the tendency to simplify the complexity that characterizes both phenomena of development and social inequality. The aim of the present paper is to contribute to a debate on the implicit and explicit conceptual and methodological assumptions underlying the current neurocognitive research on social inequality.

Some of the difficulties of studying SES stems from its inherent spanning over many different areas of expertise, which implies the need to establish interdisciplinary efforts. However, often the integration of information occurs only after the building of substantial databases. Particularly, in the context of the study of SES, that database is growing rapidly and there is an urgency to view the complexity of the problems in question from as many levels as possible. As proposed by several researchers in this field (e.g., Anderson, 1999; Bornstein and Bradley, 2003), the principles of convergent and reciprocal causation help to explain how different levels of analysis (i.e., molecules, cells, systems, individual and social behavior), may contain different patterns of interacting risk and protective factors. For instance, a risk factor present in a context of development—e.g., a rearing environment without enough stimulation for cognitive competences—may not be sufficient to cause a perturbation in the typical course of development, but the interaction between such an environment and maternal depression may indeed have that impact (for reviews and discussions of examples of these instances of cumulative/comorbidity effects, see Bradley and Corwyn, 2002; Hackman et al., 2010).

Another goal of this paper is to review the basis of the *deficit assumption* that is possible to identify in some approaches focusing on SES from a neuroscientific perspective. Many researchers working in this field explicitly mention that results—e.g., impact of poverty on cognitive performance or pattern of neural activation—do not imply any reference to a disorder or deficit. However, the model of explanation underlying some strategies of investigation does not go beyond *similarity*, by virtue of which several difficulties that children show in schools or in laboratory assessments are related to particular neural network patterns of activation that have been found in clinical populations and patients. The latter may raise an implicit prejudice or misconception any time it is applied to exclusively support research efforts aimed at finding differences that reflect negative outcomes in terms of disadvantages of one or more groups as compared to a normative group taken as criterion (Boykin and Allen, 2002, 2004). Conversely, in some other instances, it may seem reasonable that differences in patterns of neural processes between small groups of children may be a sufficient condition to infer a deficit-like condition, such as "developmental delay," even though there are no manifest differences in behaviors that define the deficit or disorder. Such interpretation is generally grounded on an assumption of underlying neurological immaturity. Yet, there is strong evidence against the plausibility of this stance. Neurological immaturity, particularly neoteny, has been long recognized as trademark of neural plasticity in the human species (De Beer, 1930; Fuentes, 2009) and the association between higher levels of cognitive abilities and delayed trajectories of cortical development in the "late bloomers" confirm that immaturity is not necessarily associated with negative outcomes (Shaw et al., 2006). Approaches alternative to the deficit assumption propose to consider the broad range of plastic cognitive processes, which characterizes human population. From this perspective, differences do not always have to correspond to deficits, as shown in intervention studies (Burger, 2010) and in alternative conceptualizations of conditions such as attention deficit and hyperactivity disorder (ADHD) (e.g., Jensen et al., 1997, 2006) and dyslexia (Geschwind, 1982, 1984).

The present paper is primarily concerned with interpreting lower performance in low-SES children, relative to their high-SES counterparts, as an indication of underlying brain deficit. Similarly, the paper is concerned with assigning low SES as a direct, univariate cause of cognitive deficits. In addition, we examine critically the nature of the still vaguely formulated deficit that generally is (explicitly or implicitly) assigned to individuals with low SES. The latter issue is addressed as a question of normativity, according to which *differences* relative to a criterion deemed as "normal" are interpreted as *deficits*. We mainly focus on the developmental human neuroscience literature which relies on findings of differences between compared groups. Our critical view of the deficit attribution does not underestimate the possibility of real deficit. We present a perspective according to which interventions are the main tool to determine real underlying deficits, since several intervention programs show that many of the lags in low-SES children's performance are neither irreversible nor inevitable.

STATE OF THE ART AND WHY IT IS TIME FOR EPISTEMOLOGICAL REFLECTION

Undoubtedly, cognitive scientists and neuroscientists would have a tremendous desire to contribute to understand and "solve the problem" of poverty with the powerful analytic tools that such disciplines can afford. Then, it is natural and genuine to foster the interest in accumulating a synthesis of the available knowledge, or the "state of the art," and translate this knowledge in action and intervention efforts (Posner, 2009).

Examples of this genuine thrust are the recent reviews by Hackman and Farah (2009), Hackman et al. (2010), Lipina and Colombo (2009) and Raizada and Kishiyama (2010), establishing consensus on the evidence base of the neurocognitive science of social inequality. Based on studies by different researchers during the last decade, these syntheses show how some experiences related to low SES or poverty during childhood are associated with behavioral performance in tasks hypothesized to be related to different underlying neurocognitive systems. Specifically, most studies use behavioral and neuroimaging methods to characterize SES disparities in specific neurocognitive paradigms. These studies are interpreted as suggesting that SES is a predictor of differences in neurocognitive performance, particularly of language and executive functions, and that these differences are found in neural processing even when behavioral performance levels are similar.

These timely reviews raise important issues and highlight the necessity of considering poverty and SES in cognitive neuroscience research as a critical developmental priority towards a scientific agenda that includes the following issues: neural plasticity, sensitive periods, epigenetics, vulnerability and susceptibility, exposure to environmental toxins, nutrition, stress response, impact of different forms of poverty on neurocognitive processing, and influences of childhood poverty on neurocognitive functioning during adult life (Hackman and Farah, 2009; Lipina and Colombo, 2009; Gianaros and Manuck, 2010; Hackman et al., 2010; Raizada and Kishiyama, 2010). That is, finally SES is a legitimate topic for serious neurocognitive scientific investigation rather than being relegated to the role of control or confound variable.

However, as in all areas of recent development it would be now necessary to also begin the review of some important epistemological and ethical issues. For instance, some of the evidence included in the mentioned reviews deserves to be explored applying alternative interpretations, and consequently contribute with the enrichment and complexities of the neuroscientific agenda. In particular, it is unclear the extent to which the available laboratory results may be interpreted as showing that low-SES related experiences may be necessarily associated with cognitive and behavioral disorders or deficits in any environmental and cultural context; and how findings may be interpreted to inform the design of different type of interventions—particularly those related to educational practices.

Although a cautionary tone permeates the mentioned reviews, still, a potential *deficit attribution*—i.e., the notion that poverty or low-SES is associated with cognitive and behavioral developmental deficits—seems almost an inevitable implicit issue (Boykin and Allen, 2002, 2004), particularly when media and scientific divulgators approach the theme even after talking with their authors (e.g., Sanders, 2008).

Despite the preliminary description of cognitive processing in terms of basic operations—which represent a scientific advance with multiple scientific and policy implications—as it could probably said by most current literature in the field, these reviews do not distance enough from a recent relative of psychometric tradition that has systematically found confirmation of intellectual and cognitive delay as part of the typical profile of disadvantaged children (e.g., Jensen, 1968). Like forty years ago, the accumulation of evidence for negative outcomes can be perceived as overwhelming, so much so that it might be recognized almost as the same "syndrome of poverty" representation (Lewis, 1967) systematically resurfaced to the arenas of social, behavioral and psychological disciplines for four decades since. Indeed, the current themes of discussion concerning research and intervention resemble strikingly those historical precedents and context when social disadvantage in children was explicitly linked with *deficits from cultural deprivation* (e.g., Hunt, 1968; see also Deutsch et al., 1968). At this point, then, epistemological, conceptual and methodological reflection is timely in order to better understand the implications of low cognitive performance in today's children everyday life and any type of intervention effort, even those conducted in laboratory contexts, and the groups of children and families that are targeted. In the following sections, we explore the nature of the evidence of SES disadvantages in current DCN, starting from the conceptualization of poverty and SES used in neuroscientific studies.

ISSUES ABOUT THE DEFINITION OF POVERTY

Social stratification notions such as "class," and the different versions of "poverty" are classic constructs for sociology, economy, psychiatry, and several other disciplines that participate in analyzing poverty phenomena. Nevertheless, there is no unique and definitive definition of general poverty, particularly, of childhood poverty (Minujin et al., 2006). It is also important to point out that there is an ongoing debate on the inconsistency with which SES is being measured in studies across the developmental sciences. Some studies have used questionnaires (e.g., Hollingshead's *four factor index of social status*), others inferred SES through the parents' educational level, the number of TV or computers at home, and others inquired about the income of the family directly. Furthermore, some studies relied on a single key proxy, such as a measure of family income, while others have used composite variables or multivariate approaches with inclusion of indicators ranging from few (e.g., five) to a large number (e.g., 25). At present, it is not clear exactly the extent to which the definitions and measures of SES are comparable, if they capture the same underlying factors and whether the results that are obtained with such definitions and measures can be legitimately synthesized under the same unitary interpretation (Duncan and Magnuson, 2012). In this section, we will selectively review just some of the inconsistencies as they apply specifically to DCN studies (for more detailed discussions see Bradley and Corwyn, 2002; Minujin et al., 2006; Bornstein and Bradley, 2003). For our scope, we will use *low SES* as synonymous of "relative poverty," however, we will use *poverty* in the instances where we want to refer specifically to "absolute poverty."

One of the most common approaches uses the specific level of income of a family to define a child's individual SES. There are inherent problems with this approach, because it views the effects of SES from a monetary standpoint and ignores the cofactors, which sometimes are better predictors of the graded effect of low SES. For example, prenatal factors such as the maternal mental health have an enormous impact on the cognitive development of a child, and cannot be reflected in the annual income of a family (Surkan et al., 2011). This approach also does not consider the composition of households in terms of gender and ages, which could adversely affect the consideration of women and children needs. For instance, it does not take into account that children have much different needs than an adult, and that the goods of the household might not be split evenly among its members (Minujin et al., 2006). More importantly, many of the things that are crucial for children healthy development are unrelated to purchasing power, and are not based on income criteria. A poverty-stricken family might still have access to clean air and water or other freely available resources. However, most poor families in many countries live in areas with toxins in their proximal environment, which have been proven to have a deep-rooted impact on human well-being since prenatal stages (Hubbs-Tait et al., 2005). For example, prolonged exposure to nitrogen dioxide—a common traffic air pollution- has been associated with reduced performance in tasks demanding working memory, motor function and coordination (Freire et al., 2010). Furthermore, severe exposure to air pollutants in urban environments (i.e., fine particulate matter $<2.5\,\mu m$ in diameter, $PM_{2.5}$) has been linked with children's cognitive impairments (Calderón-Garcidueñas et al., 2011a), white matter neuropathology (Calderón-Garcidueñas et al., 2012a,b), brain stem and auditory processing pathology (Calderón-Garcidueñas et al., 2011b) and neuroinflammation (Calderón-Garcidueñas et al., 2012a,b).

This widely used definition of poverty is being challenged by other multifactorial approaches such as the one informed by the universal principles of human rights (Barbarin, 2003; Roosa et al., 2005; Minujin et al., 2006). Human rights-based approaches usually include quantitative and qualitative indicators of access to education, health and work market, among others, and could offer a more consistent way to define poverty (UNPD, 2010). The income approach is an indirect measure of SES because it uses parental income and household wealth to measure the individual status of each child. The human rights-based approach can be applied to each child and family separately, and is a more accurate portrayal of their conditions, by being more sensitive to individual factors. This approach has also the potential to contribute to the discussions regarding the deficit assumptions in the context of the scientific community (see above), because it proposes to think about deprivations in terms of a continuum with several possible outcomes. Furthermore, in an ethical context of discussion considering poverty in terms of human rights requires to review critically the constructs of deficits, disability and potentialities.

However, even such an approach must be modified to accommodate for the different needs of children at different stages in cognitive development (Lipina et al., 2011). There is a gradient of effect according to several crucial factors such as: which risks the child was exposed to, the length of the exposure, and the child's developmental period (Evans, 2003; Gassman-Pines and Yoshikawa, 2006; Hall et al., 2010). Consequently, the definition of poverty should reflect graded effects of social inequality in interaction with developmental time-course of the child, instead of following the Extreme Group Approach (EGA; Preacher et al., 2005) in which the SES gradient is cut off generally on two halves fixed in time: poor or low-SES groups versus middle-high SES groups. It is known that EGA reduces reliability by exaggerating the differences between the groups and the individuals thereby represented.

ISSUES ABOUT VALIDITY, DEFICIT ATTRIBUTION, AND ASSIGNATION OF GROUP NORMATIVITY

As we have already mentioned, for decades, cognitive differences between poor and non-poor or low and high SES developmental samples have been reported in psychometric and educational tests, such as those measuring IQ and Developmental Quotients (e.g., Bayley, CAT-CLAMS), arithmetic and language performances (Duncan and Brooks-Gunn, 1997; McLoyd, 1998; Bradley and Corwyn, 2002). However, historically, the interpretation of IQ differences and what they really mean is still debated (Ceci, 1996; Nisbett, 2009; Stanovich, 2009). The main line of criticism is that, if interpreted as a pure measure of intelligence, as in the classic psychometric tradition, IQ tests may be biased against certain groups, which predominantly include children at the lower end of the SES spectrum.

In his review of the WISC-R—one of the most widely used IQ tests in children—Sattler (1992), proposed that most of the evidence shows that mean WISC-R scores differences between groups often confound SES and cultural backgrounds. That is, minority children may not be culturally prepared to take IQ tests, because they may not appreciate the demands, achievement stimuli, time pressures, competitive edge required, and may not see the test in the same way. Furthermore, he observed that although most IQ tests correlate with performance on educational achievement tests and, therefore, as concluded by Neisser et al. (1996; p. 93) may be said to have no "predictive bias," achievement tests are known to be unfair to certain groups in which low SES and minority status is overrepresented. Thus, the correlation between educational achievement and IQ scores could be interpreted not in terms of predictive validity but rather as a confirmation of another sense of test bias, by some called "outcome bias" (Neisser et al., 1996; p. 93) by others related to "cultural bias" in the construction and administration of the tests (Suzuki and Valencia, 1997; Suzuki and Aronson, 2005) and yet by others differentiated as "fairness" (Helms, 2006).

In addition, a different but related line of behavioral research, has demonstrated that minority groups are especially vulnerable to the effects of social status *stereotype threats* during IQ testing (Steele and Aronson, 1995; Steele, 1997). Very recently, Kishida et al. (2012) confirmed that the modulation of IQ performance resulting from framing the test-taker's environment with explicit or implicit cues about the test-taker's stereotyped social status is correlated with changes of the BOLD (blood oxygenation level-dependent) responses in amygdala and dorsolateral prefrontal cortex.

If IQ testing reflects the modalities, tasks or abilities contingent with the assessment situation, it follows that the differences between low- and high-SES children on some IQ subtests do not necessarily or predominantly reflect differences in the assumed complex neurocognitive operations. Other types of neurocognitive processing could be involved when "background" motivational, social or noisy circumstances appear during an assessment. Thus, although not all the performance differences are biased in the same way (especially those that control for some of these confounders), it is not known the extent to which the underlying cognitive processes are more important than motivational, emotional or social ones during the assessment situation to perform well on IQ tests.

Another criticism is that low SES children may have lower IQ scores because the tests do not adequately capture how those children really function in everyday settings. Elkind (1973) suggested two possible accounts as alternatives to the attribution of deficit. One account may be that children from low-SES may develop more quickly than their high-SES counterpart to anchor all their experiences around problems or tasks that involve practical reasoning, albeit very complex (*premature structuring*). The other account may be that low-SES children may get to the same point as the high-SES children get, in their mental growth, but they may get there using *different* functional pathways (*alternate elaboration*). Hence, interpretation of the effects of low-SES or poverty as a form of intellectual deprivation or lack of cognitive stimulation should be qualified more precisely. Elkind suggested that intellectual deprivation in poor children could refer to the kind and not to quantity of stimulation. What poor children may be deprived of is the same kind of stimulation expected in middle- or high-SES children, the one that will prepare them to do well in tests and school achievements (Elkind, 1973; p. 73). On the constraint of a majority or mainstream group, our culture does value some skills over others, and the IQ tests can be considered an accurate predictor of a person's ability to succeed in the abilities most valued by such a culture (favoring middle- and high-SES, Nisbett, 2009). Because IQ tests are at least in part culturally biased, being a reflection of the dominant culture's values, the most appropriate interpretation seems that likely they are measures of normativity in our population (Vonèche, 2006).

The indeterminacies just outlined put into question that IQ differences can be used as reliable indicators of SES neurocognitive differences, if the normativity issues are not considered in the interpretation of the results.

ISSUES ABOUT DEFICIT ATTRIBUTION AND LEARNING SKILLS: AN OPPORTUNITY FOR DCN

Careful manipulation of classroom setting and teaching strategies have shown that low-SES children might not be lacking the IQ to perform accurately: approaches to learning are teachable skills that may serve to lessen the gap between advantaged and disadvantaged children in the classroom. These skills are malleable, and therefore susceptible to interventions, and generalized to other areas of children's life (Domínguez et al., 2011). When controlling for stable traits such as intelligence, it has been found that learning processes account for most of the variability of academic success in the classroom (Schaefer and McDermott, 1999). This suggests that in some circumstances, one of the main difficulties of low-SES children could be the fit between their approach to learning and the typical classroom setting.

For instance, to bring the above argument closer to the neuroscience realm, some older conditioning studies (e.g., Bresnahan et al., 1969) have confirmed that low-SES children do not tend to employ the "win-stay, lose-shift" method of learning -the strategy of keeping a hypothesis if it is proven right, and discarding it for a new one if it is proven wrong. Low-SES children tend to preserve a hypothesis based on even partially reinforced behavior, and do not adjust their behavior when proven "wrong". This failure to adapt to the "win-stay, lose-shift" strategy could be the result of overlearning. The number of confirmations after the child has learned the hypothesis makes it more difficult to shift hypothesis after partial reinforcement is introduced (Bresnahan and Shapiro, 1972). Alternatively, the reason because low-SES children tend to preserve their hypothesis may be due to their inconsistent reinforcement histories, and even if low-SES children's hypothesis is not reinforced 100% of the time, it may be reinforced more than what they are used to (Bresnahan and Shapiro, 1972). In their pivotal study, Bresnahan and Blum (1971) exposed high- and low-SES children to 0, 6, or 12 random reinforcements prior to the beginning of hypothesis formation. At 6 random reinforcements, high-SES children were making almost as many errors as low-SES children. At reinforcement number 12, the high-SES sample performed just as badly as the low-SES sample. This suggests the devastating effect of chaotic reinforcement on children ability to shift and form hypothesis, and may offer a possible explanation regarding why low-SES children have difficulties in this area. Overlearning may also contribute to the gradient of SES effect on cognitive development, since the longer a low-SES child spends in a chaotic environment, the harder it is to adapt the structured academic world (Maxwell, 2010). Both groups of children employ cognitive strategies, but low-SES children would be more predictable. They seem to base their responses on the previous reinforcement, rather than attempting to figure out the odds (Silverman and Shapiro, 1970). However, it has been shown that when the more complex shifting reinforcement strategies are rewarded, then all subjects—whether low- or high-SES—switch to them (Bresnahan and Shapiro, 1972), and, in particular low-SES children show a much faster extinction period than their high-SES counterpart when rewards are eliminated.

This line of evidence is consistent with current research approaches on cognitive flexibility (Lipina et al., 2005; Clearfield and Niman, 2012) environmental chaos (Evans and Wachs, 2010) and adaptive executive attention (Mezzacappa, 2004; D'Angiulli et al., 2008a,b). Recently, literacy and numeracy skills have begun to be approached by DCN and Educational Neuroscience as well (Blair and Razza, 2007; Battro et al., 2008; Lipina and Sigman, 2012), constituting a fertile field to reanalyze some of the mentioned hypothesis from a neuroscientific perspective. There are now better opportunities to test the continuity between basic skills or preferences of information processing, which sculpt learning very early outside the schools (Blair, 2002), and the ways in which rules are understood and manipulated later on, inside and outside the schools, contributing to how children learn and think in everyday life.

ISSUES ABOUT DEFICIT ATTRIBUTION, CROSS-CULTURAL NEUROPSYCHOLOGY, AND THE INTEGRATION OF COGNITIVE AND BRAIN ACTIVATION LEVELS OF ANALYSIS

A branch of neuropsychological research extending the classic work of Luria (1976) has focused on establishing more direct links between families SES as it is embedded in the sociocultural context, especially in literate versus illiterate groups, and neurocognitive functions. Using batteries of neuropsychological tests, Ardila and colleagues (Roselli and Ardila, 2003; Ardila, 2005) have built a knowledge base on the interactions between social environment and the development of neurocognitive abilities during the life-span (for a comprehensive overview see Uzzell et al., 2007).

Nevertheless, behavioral measures do not fare any better since they are indirect and too global to be reliably put in correspondence with circumscribed focal brain deficits of the size picked up by, for instance, magnetic resonance imaging (MRI). The link between a focal lesion and the large dynamic networks could possibly be empirically incommensurable (Logothetis, 2008) and could only be proven by direct manipulation of the "black box" (Farah, 1994), such as systematically and selectively impairing a neural network to observe how the resulting focal brain damage directly affects the intervening process. Thus, these correspondences are at best suggestive and grossly approximate.

Confronted with the issues of indirect, inferred evidence, several investigators have turned to different neuroimaging techniques. One of these, the evoked-related potentials (ERPs), a non-invasive, child-friendly and relatively inexpensive technique, allows researchers to capitalize on the greater sensitivity of ERP compared to behavioral measures, and exploring differences between groups across different measurements of a same construct (i.e., attention). For example, Stevens and colleagues (2009) found amplitude differences between high- and low-SES children to probes in an unattended channel, yet both groups had equivalent comprehension and memory performance for story presented in the attended auditory channel. Thus, these findings may suggest that group differences in distractor suppression arise from differences in attentional modulation at early stages of perceptual processing (i.e., within 100 ms of stimulus presentation), confirming how ERP measures are able to detect differences (i.e., with millisecond accuracy) that may not be observable with the usual behavioral measures used in most laboratories.

In another study by Kishyiama et al. (2009), high- and low-SES groups were equated on standardized norms from neuropsychological tests. The predictions and interpretations of these findings were based on considerable evidence concerning two specific attention-related processes (i.e., novelty and prefrontal-dependent extrastriate responses, e.g., Barcelo et al., 2000; Yago et al., 2004). Consistent with ERP measures of target detection, they found no group differences in behavioral target (novelty) responses (which does not imply that behavioral differences do not exist, as other studies have been verifying in the last decades) but supported the hypothesis that group differences would only be observed in prefrontal-related neural responses. The latter results have been also interpreted as demonstrating that observed differences in prefrontal-related ERP responses cannot be attributed to task difficulty (see Hackman and Farah, 2009).

The most important contribution of these studies is the demonstration of the importance of analyzing the influences of SES on neurocognitive performance simultaneously according to at least two level of analysis: (1) behavior, and (2) concomitant neural activation. However, at the same time these types of analyzes illustrate some epistemological difficulties on what DCN should incorporate in its agenda. Both studies seem to make different assumptions on the measured ERP waves that induce a sort of confusion of the level of analysis of the explananda. It is possible that they confound the level of brain activation with the level of functional organization of complex cognitive or mental events (e.g., cognitive control). The latter cannot be operationalized in well defined sets of single operations, or put in correspondence with large regional changes of activation, which in turn are characterized by large individual differences and are directionally ubiquitous—can correlate with both positive or negative polarities in ERPs (or activation and deactivation in fMRI and PET). There is now a considerable literature demonstrating that no currently available single neuroimaging technique affords such a fine resolution grain to directly portray *how* the flow of information is organized for complex cognition. That is, showing where and the extent the information is used does not elucidate how the brain uses it for cognitive operations (Roland, 1993; Sartori and Umilta, 2000; Servos, 2000; Logothetis, 2001, 2008; Faux, 2002; Krekelberg et al., 2006).

In some neuroscientific reports, it seems that the role of the analysis of behavior and functional organization may be considered as ubiquitous, whether low-SES children do or do not perform similarly to middle or high class children, their brain is almost expected not to be activated as efficiently as it should (see D'Angiulli and Lipina, 2010; and Jensen, 2009 for examples of such an assumption). But in the absence of morphological abnormalities, departure from typical brain activity in low-SES individuals can only be validated in relation to an external objective criterion of low performance. It would be interesting to analyze to what extent these assumptions were or not inherited from the behavioral studies on the effects of SES on behavior, school achievement and IQ, which also have tended to hinge on the effect of normativity. That is, low-SES samples differ from typically developing children belonging to middle-class majority group, therefore, this could be interpreted as a delay, an impairment or just atypical. Another potential implication of this suggested inheritance could be that in some neuroimaging studies is considered as a plus-value point when children from disparate SES backgrounds achieve the same levels of behavioral performance. Despite the advantage of identifying apparently pure neural measures indicating activation differences, such findings do not necessarily imply that neural differences are deficits. In other words, deficits cannot be presumed in samples of low-SES individuals only based on brain differences (Elkind, 1973).

Another type of epistemological issue would be represented by those studies that equate patterns of activation from different types of populations, such as brain-injuried patients, with low-SES children. For instance, in the Kishyiama et al.'s work (2009), the background research (Barcelo et al., 2000; Yago et al., 2004) supporting the brain wave and top-down mechanism considered is based on very controlled but rather small studies with stroke patients and adults. The comparison between stroke patients and children from low-SES backgrounds would present some epistemological issues. First, it did not address how age modulates the associations between SES, behavioral performance, and brain activation. Second, the use of lesion models or references would induce the assumption that dissociation techniques prove localization. However, behavioral changes from damage to a certain part of the brain, does not indicate sufficiency. That is, consistent with *pluripotentiality* (Luria, 1964, 1966) and *neural reuse* principles (Anderson, 2010), the affected areas of the brain could be contributing crucial information, but the changed function may not necessarily be all or even partially represented in that area, but in a chain of complex temporal and spatial networks dynamics. Another example of this argument would be the Noble and colleagues finding that the Left Perisylvian/Language System is shown to have a significant correlation to SES variation (Noble et al., 2006), if by over-interpreting we could forget that the "Left Perisylvian/Language System" was proposed by the authors as a broad operational construct, that correlation could be also put in direct correspondence with differences in focal brain functions in left hemisphere structures specialized for language, such as Broca's area (Raizada et al., 2008). However, although speech functions are assumed to correspond to a decidedly contained region, a large variability in lesion patterns and speech disturbances have been observed (Hojo et al., 1984) and Broca's area has been implicated in functions other than speech, such as tool use (Higuchi et al., 2009). Furthermore, the developmental validity of hypothesized neurocognitive systems such as the Left Perisylvian/Language System really comes from few non-longitudinal studies with results from variable samples, implying that behavioral evidence of neurocognitive differences between SES groups, especially in preschool children, are still tentative at this point.

There is also the issue of a certain circular logic in defining cognitive processes. The research would induce these processes from task-dependent behavior, but the formation of these tasks require prior knowledge of the sought after process. This previous inferred knowledge can taint the experiment and produce results that seem valid, only because they could validate the researcher's expectations in the first place. Such circularity can be particularly problematic for research on SES. For example, in the Stevens and colleagues study (2009), the described cognitive performance is related to a very complex semantic comprehension listening task, which engages various components of working memory, yet the positive wave differential effects which much of their analysis focuses on is interpreted as mostly reflecting early attentional processes. Consequently, it would be important to be cautious before confirming the involvement of only one type of cognitive process, in order to contribute with a reliable epistemological validation of psychological constructs—especially when

SES issues are involved for the implications of equally valid alternative conclusions. Finally, some methodological decisions could highlight the negative aspects of different cognitive processes when applying rigorous exclusion criteria that results in samples with disparate health or performance conditions (Hackman et al., 2010).

INTERVENTION EFFORTS AND DEFICIT ATTRIBUTION BIASES

Although middle- and high-SES children also could experience socioemotional and behavioral/cognitive issues related to atypical development (e.g., Luthar, 2003, 2006; Luthar and Latendresse, 2005; Ansary and Luthar, 2009) they are not frequently and promptly seen as eligible for interventions, if not within the realm of universal public health and education. However, low-SES children are mostly seen as eligible for many types of interventions worldwide. By far this protective attitude is absolutely necessary and warranted, because the social inequities produced by each society systematically violate children basic rights, gradually eroding their developmental opportunities, to the point of being stigmatized and excluded from society (UNICEF, 2005). However scientists need to take responsible decisions regarding the eligibility to intervention, by considering that interventions, especially in the area of DCN, involve several issues that require the inclusion of children from all socioeconomic backgrounds (Jolles and Crone, 2012).

Lack of awareness of the potential biases associated with the deficit attribution and normativity conformism can support practices that perpetuate inequalities and potential neglects. Experimental interventions targeting neurocognitive functions could be speculative if simply arise from proposals based on unfocused evidence of correspondence with brain functions. Rather, it would be important to identify potential contributions of experimental interventions aimed at optimizing cognitive, emotional and learning processes of low-SES populations to foster inclusion in their community and institutions.

At present, the available evidence about the cognitive gains after training in laboratory contexts [e.g., Rueda et al., 2005 (attentional training/healthy children); Wilson et al., 2006, 2009 (arithmetic training/dyscalculic children); McCandliss et al., 2003; Temple et al., 2003; Shaywitz et al., 2004 (attention and phonological awareness/dyslexic children)], or school/community intervention programs aimed at optimizing cognitive development (e.g., Perry Preschool, Abecederian, Chicago CLS, Tools of the Mind, Harlem Children's Zone, etc), suggest that neurocognitive plasticity, even considering the current limitations in knowledge and specificity, could be modulated through multimodular complex interventions which include sociocultural contextual variables. Therefore, any statement that implies the idea of a low performance-physiology associated with a lesion process is not necessarily correct. Both can be circumstantial and more studies and new methodologies are needed to better understand several related issues. In this sense, DCN would benefit from multimodular programs that have been shown to be effective in improving low-SES children social inclusion, such as Tools of the Mind (Bodrova and Leong, 2001), Harlem Children Zone (Raver et al., 2008; Tough, 2008).

MEDIA IMPLICATIONS OF DEFICIT ATTRIBUTION AND NORMATIVE BIASES

Media divulgation of DCN studies on childhood poverty could also disseminate the deficit attribution and normativity assumptions to the public. The latter, in turn, can induce the generation of *myths*—as commonly held, but erroneous beliefs—about brain development and the influences of environment and parenting. Once consolidated, the myths require much effort to be eradicated, often requiring the involvement of many professionals, including the neuroscientists (Bruer, 1997). Among the reasons that facilitate this type of undesirable effects, is the lack of discussions among scientists on how to inform media about research findings, although some important efforts have been made in the last years (see Thompson and Nelson, 2001; Illes et al., 2010).

An example of such a dangerous dissemination is an article by Sanders (2008) appeared under several online press subsidiary outlets with associated links and citations which currently still give thousands of hits in Google. While reporting about the study by Kishyiama et al. (2009), the journalist first mentions the following comment by one of the authors: "Kids from lower socioeconomic levels show brain physiology patterns similar to someone who actually had damage in the frontal lobe as an adult." The quote continues: "We found that kids are more likely to have a low response if they have low SES, though not everyone who is poor has low frontal lobe response." Then, another author is reported to have said, "These kids have no neural damage, no prenatal exposure to drugs and alcohol, no neurobiological damage…" "Yet, the prefrontal cortex is not functioning as efficiently as it should be. This difference may manifest itself in problem solving and school performance…" "Those from low socioeconomic environments showed a lower response to the unexpected novel stimuli in the prefrontal cortex that was similar … to the response of people who have had a portion of their frontal lobe destroyed by a stroke."

To the extent that the alleged verbatim quotes could be trusted, the reference to an association between deficit (prefrontal impairment) and poverty seems clear. However, the results of one single laboratory experiment—with small sample of children from different SES and confounding mixed minority backgrounds—cannot support definitive conclusions. It seems that the mentioned potential mistake in the distinction between different levels of analysis (i.e., behavior, neural activation)—which deserves to be an issue of discussion among scientists in the realm of DCN—may have been omitted from the discussion. Thus, this lack of clarity in the distinction potentially induces to misleading knowledge building and/or scientific divulgation about what poverty really means in the life of children that suffer it and the reversibility or not of the behavioral and neural activation findings.

The same could be said regarding the scientific foundations of interventions based on brain studies. For example, in the same interview, another author is reported having said: "But changing developmental outcomes might involve something as accessible as helping parents to understand that it is important that kids sit down to dinner with their parents, and that over the course of that dinner it would be good for there to be a conversation and people saying things to each other." This statement includes many assumptions that should be discussed critically in the neuroscientific agenda. First, those kinds of intervention statements probably are true but could fit quite loosely the findings of the many intervention studies that have been conducted in the last five decades, rather than specifically in the emergent field of childhood poverty and brain development. Second, as mentioned, there are many environmental and cultural constraints that could put in question the plausibility of what is suggested parents should do or be like, since poor parents in many developing countries cannot chose to freely engage in those actions (UNICEF, 2012).

To complete the circle, developmental cognitive neuroscientists should also consider that they may not just be at the input stage of the vicious cycle. They may be, like journalists and everyone else in this media-dominated society, also at the receiving end. It is striking that many of the implicit assumptions discussed in this paper could be predicted by watching popular TV shows, such as The Simpsons. Low-SES working class individuals are often portrayed as unintelligent, hence having poor taste, as well as lazy, and incompetent—especially as parents and providers—and cognitively rigid, in political and religious senses (Alper and Leistyna, 2005; Leistyna, 2009). Also, it would be hard to miss the analogy with intervention in the many reality shows that focus on improving the low-SES individuals through "makeovers" targeting all the areas that portray the TV stereotypical social class profiles (Leistyna, 2000; Miewald, 2001; Fink and Lomax, 2012). It is only fair to ask whether any subtle influence creeps into our science feeding back a predisposition to certain default assumptions in the way we approach the very object of investigation. One thing is clear, if media as powerful as TV and online newspapers may already have a background predisposition to consider poverty and low-SES in a certain way, then neuroscientists should be most careful with how to communicate and disseminate the findings, interpretations and conclusions of their studies.

Excellent journalistic reporting of science does exist and is becoming more common even in fields so politically and socially charged as those dealing with poverty (see for example McIlroy, 2010). For effectively translating neuroscience to communities, excellent journalism may very well turn a dangerous weapon into a golden opportunity.

DEFICIT ATTRIBUTION, DEVELOPMENTAL DISABILITY AND INTERVENTIONS

FROM DEFICIT ATTRIBUTION TO ADAPTATION

As mentioned, there is no question that low-SES children could benefit from intervention programs aimed at optimizing their developmental opportunities. However, many issues in the realm of interventions should still been analyzed very carefully. For example, it seems that the immediate gains of some interventions go through a "fade out" process. That is, while the results show clear gains within the first months after ending interventions (higher IQs, particularly), successively, these benefits seem to fade and disappear when the children are retested years later (Raizada and Kishiyama, 2010). Interestingly, although IQ points seem to revert back to baseline, children that attended intervention groups seem to have acquired a sort of "grit": a larger percentage of them later in life are employed, graduate from secondary schools, end up in stable and good employment, and have enough purchasing power to afford dwellings and other personal properties (Knudsen et al., 2006).

The pattern of "gains-losses-gains" has many different kinds of implications. Regarding the neuroscientific agenda in the study of childhood poverty, there is a need to design studies that will permit to explore and analyze what kind of plasticity patterns could explain such changes.

This area of research also implies the analysis of plastic processes related to potential sensitive periods for many aspects of emotional, cognitive, language and social development. From another perspective, this pattern of gains and fading processes also justifies the need to analyze what kind of intervention contents in each module of a program is related with what type of outcome. For example, are the intervention programs that obtain these long-term desirable outcomes more oriented to self-discipline or commitment to learning, or social values? In such a case, any DCN agenda focusing on SES not only should include genuine interactions with disciplines which feature preeminently in the now so-called *learning sciences* (such as education, sociology, and anthropology) but also disciplines that offer alternative frameworks of explanation (for example, population genetics, ecology, and evolutionary biology). Furthermore, as Jolles and Crone (2012) have highlighted, many confounding factors should be considered when interpreting training effects, mostly falling in two categories: (1) *general confound factors*: familiarity, expectancy effects, shared components between the context of trained and transfer tasks, motivation, feedback and reward, and cohort effects; (2) *factors specific to neuroimaging*: such as task performance, task irrelevant processing, awareness of task, morphological changes, "scanner" anxiety, and performance on the scanner.

Many current intervention programs (see section "Intervention efforts and deficit attribution biases") conceived within DCN have been designed to target preferential neurocognitive functions involved in learning acquisition and basic cognitive operations deemed to support literacy, numeracy and social skills. These interventions were at first conceived for the entire population of children, but most recently there has been a shift to tailor interventions for low-SES children with the rationale that their basic skill development could be optimized (Lipina and Colombo, 2009). The priority has become preventing developmental learning/achievement disabilities that have been found to covary with or be outcomes of SES (e.g., Bradley and Corwyn, 2002). The relationships that connect intervention and SES via the concept of disabilities are instrumental to have a concrete term of reference in place of the vague, fuzzy "deficit-like" condition that looms behind the deficit attributions. Hypothetically, we can assume that the deficit underlying underperformance and non-normative brain responses in low-SES children may, in a form or another, end up manifesting as a developmental disability. Then, we could begin to address the question of how deficit would be concretely defined, understood and dealt with from a perspective that integrates DCN and allied disciplines.

Indeed, the model of deficit that underlies ongoing debate on the construct and status of developmental learning disability in some disciplinary arenas, i.e., education, has shifted the focus increasingly to what resembles an "adaptionist" conception of human abilities and performance (Levine, 1992; Gardner, 1999; West, 1999; Sternberg, 2000; Kalbfleisch, 2004). According to this focus, every *neurocognitive preference* has strengths and weaknesses, depending on the conditions at hand (Blair, 2002; Schibli and D'Angiulli, 2011), which fits the model of parallel non-mutually exclusive continua that could go from dis-ability to hyper-ability (giftedness) depending on the structured interactions between specific experiences and environments in which individuals grow, live and go to school (Maggi et al., 2004; D'Angiulli et al., 2004a,b)—what decades ago Barker (1968) grouped under the term "behavioral settings." Nevertheless, the spectrum of potentialities apparently is preserved in order to effectively supply our population with a diverse repertoire of adaptive possibilities (Geschwind, 1982, 1984; Gilger and Hynd, 2008). As examples, let us consider two of the most typical developmental disabilities that are increasingly consistent with the adaptionist scenario (West, 1999): ADHD and dyslexia.

ADHD is characterized by inattentiveness, hyperactivity and impulsivity (American Psychiatric Association, 2000). Like in the considerations of low-SES, impairment of executive function is the most prominent account for ADHD symptoms. This hypothesis, however, is criticized because, despite the substantial database of behavioral and neurological tests on ADHD, there are many contradicting findings (Willcutt et al., 2005). For example, memory is one of the supposed deficits. However, this seems to be context-dependent for working memory (Lawrence et al., 2002) or non-existent for long-term memory (Kaplan et al., 1998).

Yet an alternative conceptualization (Jensen et al., 1997, 2006) conceives the features of ADHD as evolutionary advantageous traits derived from behavioral settings in ancestral or tribal hunter-gatherer societies where hypervigilance and hyperactivity, divided attention, and attentional scanning of the surrounding environment represent important parts of readiness to flight/fight response, which would augment the likelihood of survival. However, the latter is a hypothesis that still needs empirical confirmation.

One does not need champion evolutionary psychiatry, some other research, for example, has converged on the overlap between children who appear to be highly creative and children diagnosed with ADHD. Recent tests have shown that people with high levels of creativity often score low on measures of latent inhibition (Carson et al., 2003). It has been argued that it is because of lack of such type of inhibition that these individuals are able to problem-solve so creatively. It seems that these individuals have a genuinely different way to negotiate distinct competing sources of information and how it is then used for higher cognitive activities such as thinking: environmental cues seem to overwhelm the influence of internal elaboration, and produce vastly different responses than in less creative people. Specifically, Abraham and colleagues (2006) found that children with ADHD could overcome constraints of recently shown examples and create unique imagery. However, when asked to imagine an object from three different shapes, they failed to produce a practical one. That ability to think freely without the influence of rules or constraints is a fundamental characteristic of problem solving which has well supported neurocognitive basis (Shallice and Cooper, 2011), furthermore, several real-life case studies confirm it is associated with excellence in business, science, art and innovation (West, 2003). Although the evidence suggests promising possibilities, much empirical work is needed to flesh out the adaptionist perspective on creative reasoning and problem solving in individuals with ADHD.

The second example, dyslexia, is characterized as a reading learning disability. Generally, many children with dyslexia show language acquisition delays; they have trouble retrieving words from memory, mastering grammar, planning and organization. Moreover, they frequently have low processing speed, time awareness, focus and error detection (Pugh and McCardle, 2009). One of the most influential accounts for the symptoms is the phonological core account, according to which the difficulties with reading and writing stem from impairment in segmenting and discriminating patterns of phonemes (Stanovich and Siegel, 1994). Although such account considers individual differences, it seems that would not easily accommodate some of the other deficits found with dyslexia, such as poor finger coordination and eye movement while reading (Wolff et al., 1990; Bucci et al., 2012) and a very recently reported deficit in procedural learning which would make imitating and learning routines exceedingly difficult for children with dyslexia (Nicolson and Fawcett, 2000).

Geschwind (1982, 1984) and Geschwind and Galaburda (1987) were the first to propose an adaptionist view of dyslexia—and by virtue of the frequent comorbidity between the two, indirectly of ADHD as well. They proposed that genetics and in utero hormonal activity modified neurodevelopment and hemispheric specialization such that a person could be born with a brain wired to be at risk for dyslexia but at the same time with superior nonverbal abilities. They and others have proposed that the setting of the left hemisphere language areas to be prone to language-based impairments could in fact affect the growth of portions of the right hemisphere such that there might be an overrepresentation of nonverbal giftedness in samples of dyslexic individuals. Thus, on this view, gene-brain-environment interaction yields neural strengths and weaknesses, which, depending on the behavioral settings, can translate into socially defined talents and disabilities. Indeed, there is growing evidence that dyslexic individuals do seem to have selective, but very subtle and specific advantages for the span of visuo-spatial attention (Geiger and Lettvin, 1987), speed in performing global evaluation of complex visual stimuli (von Károlyi, 2001; Winner et al., 2001; von Karolyi et al., 2003), and visual comparisons (Schneps et al., 2007).

Early studies of dyslexia supporting Geshwind and Galaburda's thesis suggested that deficits in reading originate from an alternate neural circuit, which relies heavily on the right hemisphere (e.g., Yeni-Komshian et al., 1975). This hypothesis has since been modified and redefined as an interhemispheric connectivity issue affecting primarily the angular gyrus, which is hypothesized to be an important circuit linking visual association areas with language centers, especially, Wernicke's area (Horwitz et al., 1998). The lack of "short" interconnections in the angular gyrus may be explained by the broad spacing found in the minicolumns of dyslexic patients' brains by Casanova and colleagues (2002a). A slight change in the functional minicolumn structure would have widespread effects across the brain, impacting connectivity between areas of the brain, and, in doing so, information-processing functions (Casanova, 2010; Casanova et al., 2010). The alternative circuit in dyslexic patients may be the result of a distinct shift in processing, which appears to be most detrimental during phonological decoding (Simos et al., 2000). Other structural differences found in brains of individuals with dyslexia could be explained by a general change of minicolumn morphology. The brains of individuals with dyslexia show decreased gyrification, and atypical lateralizitazation (Rumsey et al., 1997), as well as a wider gyral window (Casanova et al., 2010). Structural processes such as lateralization and gyrification may result from an addition of minicoloms within the isocortex (Casanova and Tillquist, 2008), and a wider gyral window allows for longer cortico-cortical fibers and spaced out minicolumns (Casanova et al., 2010). Only future research efforts will tell whether minicolumnar structure and organization are indeed linked to cognitive functions and preferences (Casanova, 2010), thereby, addressing some of the same limitations we have discussed in section "Issues about deficit attribution, cross-cultural neuropsychology and the integration of cognitive and brain activation levels of analysis."

Can the adaptionist explanatory framework be extended to low-SES children? Consideration of such a possibility is scant but does exist in the literature, with supporting behavioral evidence (e.g., Buckner et al., 2009, 2003). Some neuroscientific support comes from aforementioned ERP studies on executive and selective attention in children living in poverty-stricken and inner city neighbourhoods. For instance, there is consistent accumulating evidence that Low-SES children attend both to relevant and irrelevant information employing in the process more intense and longer effortful control than high-SES counterparts (D'Angiulli et al., 2008b; Stevens et al., 2009). We have argued that in the behavioral settings in which these children live (chaotic, noisy, and threatening) indiscriminate attention and monitoring of environmental cues ("ear-to-the-ground") may actually be adaptive for detecting dangerous or unwanted situations, to trigger in a top-down fashion appropriate fight/flight responses (i.e., D'Angiulli et al., 2008a,b). However, similarly to the evolutionary advantage of ADHD traits, the latter hypothesis also needs further empirical confirmation.

DEFICIT ATTRIBUTION, DISABILITY AND SOME ETHICAL CAVEATS OF INTERVENTIONS

The ability of our brains to adapt to a quickly and constantly changing environment is one of the reasons why humans have become a complex species with a high range of adaptability (Bednarik, 2011). However, it is difficult to demonstrate the adaptive potential of many neural processes other than those involved in literacy and numeracy because until very recently, the emphasis has concentrated mostly on inter-group differences in those subjects. We should ask whether the difficulties to filter information normatively as shown by some low-SES children, for example, could also coexist with high imagination competency or higher spatial situational awareness and physical agility in their own environments not picked up by mainstream research methods (e.g., Nunes et al., 1993). The fact that laboratory tests may fail to mimic some potentially key ecological dimensions of real-life environments is just one confound that is not properly addressed and that could be improved with approaches combining longitudinal behavioral and neural activation measures in behavioral settings.

We do not condemn intervention efforts, but rather suggest a critical take on them, to integrate adequately and genuinely the contribution of many scientific approaches that responsibly are trying to improve ways to study childhood poverty, as per DCN community. For instance, instead of seeking to only change the child, the education system could benefit by adapting to accommodate for different neurocognitive preferences, such as DCN studies on individual variability show. For example, a study by Lawrence et al. (2002) on ADHD children in a natural environment showed that the deficit in working memory does not appear while the children were playing video games. They suggested that continuous feedback and reinforcement in the form of visual and auditory cues, as well as the opportunity to self-pace, alleviated the strain on working memory enough for the children to perform well. On the other hand, dyslexic children have an easier time with explicit learning and having the explicit rules broken down into manageable steps, instead of imitating a full routine. This kind of information would be helpful for teachers with not only dyslexic and hyperactive children, but also with all children who have trouble with working memory or procedural learning, including some low-SES children. This kind of approach can help lessen social pressures on low-SES children in contexts such as those inducing the pygmalion effect (Rosenthal and Jacobson, 1968).

The effect of a teacher's bias on the performance of children in the classroom has been known since many years ago (e.g., de Boer et al., 2010) and although the original pygmalion effect needs substantial revisions, the most recent reviews confirm that stigmatized groups such as African-Americans and children from low-SES backgrounds still continue to be sensitive to the expectations of their teachers, and do poorly when there is an assumption of failure (McLoyd, 1998; Jussim and Harber, 2005) spending extraordinarily more energy negotiating for their image in society than their middle- or high-class counterparts (Stephens, 2010) with increased odds of learned hopelessness or helplessness (Ursin and Eriksen, 2010).

Thus, it is important to consider and reflect about the responsibilities of the scientific community to prevent harmful myths, prejudices, misconceptions, and how some research may be, even if unwillingly, contributing to them. If some of the assumptions and attributions we consider here may not only be seen in the case of low-SES children, being connected with the conceptualization of developmental disabilities such as ADHD and dyslexia, we could observe again a pattern where "difference" seems interpreted as "deficit." Nevertheless, based on what we learn in the comparison with these disabilities, the conditions associated with low-SES could at some level be defended as having an adaptive role even considering a deprived environment—which definitively implies an unethical circumstance.

If interventions can be created which have an impact on underlying neural processes, the crucial questions still remain: do we want to change the atypical neural preferences to normative ones? And in such a case, as it may apply to low-SES children, what are the foundations of our intentions as scientists? Are we being careful in not hastily putting the horse of intervention before the cart of understanding? These and other poignant questions regarding interpretation and translation of research results, as well as their far reaching implications, overlap remarkably with the most recent debate regarding ethical, legal and social issues in neuroethics (Illes et al., 2006). However, while the debate over the clinical use of neuroimages is right now very much alive, a parallel debate on the neuroethics of intervention is overdue in the DCN of SES.

LIMITATIONS OF THE ADAPTIONIST PERSPECTIVE

The adaptionist perspective is not immune to problems. Thus, to rebalance our critical review, we need to consider a few of its shortcomings here. One major issue is that very few research efforts have consolidated the adaptionist evidence-base, and most of the hypotheses need much more empirical testing and corroboration (as we did note in previous sections). The adaptionist perspective is based on an underlying assumption of complexity that preserves a general determinism (for example, probabilistic as in dynamic systems). However, cannot be mapped or decomposed easily into strict causality relationships (Bunge, 1979). Therefore, it does not offer very transparent explanations that give compelling accounts for indirect effects associated with low-SES environments. For example, it is not clear how certain variables associated to low SES such as inadequate nutrition can be incorporated in adaptionist models. Neurobiological and neurophysiological studies have shown that a poor diet during pregnancy and/or during the infants' first months of life can induce anatomic and functional development problems in the brain (e.g., Morgane et al., 1993, 2002; Georgieff, 2007). In some cases, low-SES participants may be facing real brain deficits that later might have irreversible consequences on their performance on cognitive tasks (e.g., de Souza et al., 2011; Waber et al., 2011; Galler et al., 2012). The same goes for the neurotoxic effects of theratogens and pollutants (see section "Issues about the definition of poverty"). Which aspects could be considered adaptive in these circumstances? If adaptionism is not related to the ecology of the living conditions (the behavioral settings) then the explanatory power of that approach is quite limited.

Although there is no need to link adaptions to evolutionary advantages, which by themselves have problems of falsifiability and possible ideological confounds (e.g., the implicit assumptions of positivistic progress, see Searle, 1995), it is difficult to empirically validate what is or not adaptive in a given situation, and decisions on what is or not adaptive may ultimately appear to be nothing but arbitrary.

Related to the previous criticisms, one implication is that the adaptionist perspective can be easily misinterpreted as a form of extreme relativism minimizing real challenges that certain groups are likely to encounter. This in turn may actually be harmful to children who do have actual deficits and do actually need support.

In sum, adaptionism can be as speculative as the deficit assumption. If misinterpreted or misused, it may be perceived as or actually become a roadblock to advances in the field of intervention. However, some aspects of the definition of adaptations can be improved and falsifiable, we explore further these features in the next section to propose a framework in which they can constructively enhance, not stonewall, the approach to interventions.

SOME POSSIBLE ALTERNATIVES AND FUTURE DIRECTIONS

EXPERIMENTAL INTERVENTIONS AND REAL DEFICITS

If adaptionism is properly examined in ecological settings, the idea of deficit can be redefined as a variable set of environmental conditions experienced by low-SES participants which becomes a detrimental factor in preventing optimal brain development, possibly resulting in irreversible neurocognitive impairment. This conceptualization does not underestimate the possibility of "real" deficit; and permits to incorporate experimental interventions as a way to measure deficit in a non-normative fashion. That is, experimental interventions could be the main tool to determine the extent of reversibility, and conversely, plasticity, since with the appropriate intervention a low-SES or poor child's performance could catch up with that of the higher SES counterparts. In this way, it would possible to identify real and essential deficits as a miss or break down of adaptation. Accordingly, possible neurocognitive deficits could be identified without sidestepping ethical issues (since intervention may be offered to children from all SES background as a preemptive form of support), and without relying on value-laden normativity criteria. Conversely, such approach would also permit to properly evaluate the extent of deficit even in some instances of extreme early or chronic deprivation, for example some forms of malnutrition whose effects are at least partially reversible with early intervention (e.g., Martorell et al., 1994).

TOWARD AN ECOLOGICAL DEVELOPMENTAL COGNITIVE NEUROSCIENCE FRAMEWORK

Approaching the implications and issues that deficit attribution and normativity have in the context of an interdisciplinary DCN research agenda, focused on child development, biological and social determinants, implies starting from a wide conceptualization. Such framework should make provisions for multiple levels of analysis, explanations in terms of interactive complex mechanisms situated in turn within a systemic, comprehensive, and coherent approach incorporating ecological perspectives (e.g., Barker, 1968; Bronfenbrenner and Ceci, 1994). Thus, we propose that an ecological developmental cognitive neuroscience (eDCN) framework would be necessary to promote a visualization of child development, developmental processes and social determinants thereof as complex phenomena. The construction of a common language dealing with child development and determinants (i.e., biological, social, and cultural) in ecological terms would be a first, necessary step toward the construction of academic networks apt at informing about both the design, and implementation of comprehensive, coherent experimental interventions.

Consistent with eDCN, ecological and transactional considerations on child development and determinants should contribute to build a research agenda with at least the following updated issues:

(a) *Identifying different problems and risk factors levels for both basic and applied research*. For example, considering ecological theories, the complex set of problems and risk factors characterizing the biological, psychological and cultural determinants of low-SES child development would offer researchers a basis for organizing research agendas, with focus on development as a complex phenomenon, being integrated into different conceptual, methodological frameworks, and being applicable within different, sociocultural contexts.

(b) *Reconceptualizing measurement of child poverty*. Conceptual and operational definitions of poverty are unlikely to capture either specific information on the deprivation children are subjected to, or to associate deprivation with different developmental phases and dimensions. Specifically the level and type of deprivation, as well as brain developmental stage at the time of deprivation, may modulate the impacts. As mentioned, several studies have advised that children exposed to poverty must be taken into account as independent analysis units as they are exposed to poverty's effects in a different way than adults or other children (Gordon et al., 2003; Roosa et al., 2005; Minujin et al., 2006). Although these studies improve the comprehension of how poverty affects child development, they still do not take into account the interrelationship and interdependence between phases, contexts, and dimensions of development. At present, many researchers agree that the multifactorial nature of poverty means that multidimensional measurement methods have to be adopted and adapted to child poverty. Such a demand for multidimensional definitions and measurements imposes an obligation to carefully select the measurement methods: questions, hypotheses, and study objectives aimed at analyzing child development processes in both research to identify, describe, and research into intervention strategies.

(c) *Guiding the design of interventions in terms of different systems and dimensions involved in child development components and processes*—i.e., building an ecology of interventions through data-driven theory. In particular, the current research agenda in the DCN area suggests there is a need to analyze the emergence of different self-regulatory, cognitive, and emotional processes, their role in school learning process, their modulation in function of parents' mental health and home stimulation as well as their potential optimization through home, school, and community (Lipina and Colombo, 2009). However, we propose that this should be done systematically within a common research framework to all researchers and guided by a process of knowledge building through the formulation and falsification of data-driven theories.

(d) *Focus on promoting support for both basic and applied research on child development as the main focus.* Although financial institutions and organizations—especially those in developing countries—usually consider child development issues to be a high-priority area, there exists a lack of visualization of the complexity of such mechanisms and determinants. In addition, several types of academic inertias act in favor of some approaches at the expense of others (e.g., either Constructivism vs. Behaviorism in education-based research or environmental vs. genetic determination of cognitive competences throughout development). The latter, reduces possibilities for genuine disciplinary integrations as well as researchers' formation in new areas such as neuroscience and education. In this context, supporting efforts aimed at promoting collaborations focused on different levels of analysis would be important, such as: (1) modulation of parenting dealing with the development of self-regulatory competences; (2) analysis of the associations between teaching styles, and the development of executive control competences; (3) identification of cultural constraints for nutritional supplementation interventions; (4) integration of cognitive, emotional, and social competences stimulation when designing school curricula; (5) inclusion of art in community interventions as a tool for social and health transformations, such as for example *El Sistema* in Venezuela; or The Children Harlem Zone in New York (6) knowledge mobilization of intervention approaches across the globe.

(e) *Building capacity aimed at progressively eliminating myths, prejudices, as well as conceptual dogmatisms*. As mentioned, the lack of visibility and vision for childhood is a frequent problem in many countries worldwide that involves parents, teachers, politicians, and policy-makers. Nevertheless, it is possible to find an even more serious situation in academia. This implies an urgent need to create new instances of formation at the local and global scales.

(f) *Influencing public opinion, through the media, to promote collaboration between researchers and journalists, based on the consideration of child development as a complex, systemic phenomenon.* Part of the researchers' social responsibility lays in disseminating knowledge—hence avoiding myths to be created with regard to child development. Thus, setting up common, ethical norms so that public opinion could be informed through the media would be not only feasible but also desirable. Furthermore, training efforts could be generated such as interdisciplinary workshops, and debates—and, even, contents useful to university degree courses for Social Communication and Journalism programs as well (see Illes et al., 2010). Such efforts should also be integrated within multiple modules of intervention designs, from an ecological, transactional perspective, for example, as an integral component of activities guided by the proposed eDCN framework.

CONCLUSIONS

By no means do we argue that cognitive and behavioral performance differences between low- and high-SES children are mere epiphenomena of contrived laboratory experiments or that such differences play no part in determining children's economic and social outcomes in adulthood. Such differences have been well documented across different cognitive domains, using a variety of experimental designs and cognitive tasks. Thus, these empirical findings deserve utmost attention of developmental cognitive neuroscientists, as they are suggestive of differences in structural and functional organization of the brain as a function of the SES context in which it develops. In addition, the hypothesis that observed differences are largely attributable to cognitive deficits in low-SES children should be considered with great caution, since it could ignore the fact that different SES contexts present unique environmental challenges to which children must learn to adapt. Therefore, it seems more likely that at least some performance differences between low-and high-SES children reflect differences in structural and functional organization of the brain as a result of context-specific organism-environment interactions which potentially confer different forms of adaptions to their own environmental settings.

Taking this conceptualization seriously, it is possible to recognize that positive adaptions to one specific environment may not be generalizable to other environments, and therefore may not be congruent with them in terms of certain of their cognitive, behavioral, and socio-emotional requirements. By extension, using developmental norms of one context to assess cognitive, behavioral and socio-emotional performance of children from another context may reveal clear performance differences plausible to be interpreted as deficits. Such misinterpretation, however, is relative to diverse contexts taken as normative and therefore biased and wrong because it does not explain cognition and behavior in ecologically valid terms.

There is a variety of deprived circumstances characterized by specific ecological risk factors present in moderate and severe low-SES settings (e.g., Gordon et al., 2003) which predispose children to particular types of developmental insults, with potentially irreversible neurological consequences. A number of such risk factors have already been documented, including malnutrition, exposure to environmental toxins and severe physical and psychological abuse (Bradley and Corwyn, 2002; Lipina and Colombo, 2009). However, research in this area has exclusively focused on low-SES environments, despite the recent evidence that high-SES contexts may too predispose children to certain negative cognitive, behavioral and socio-emotional impacts, perhaps different in kind, but no less developmentally important (Luthar and Ansary, 2005; Luthar, 2006; Ansary and Luthar, 2009). Therefore, both negative and positive ecological factors should be considered at all levels of the SES spectrum.

Furthermore, it is not the purpose of the paper to discourage any type of effort to develop and implement intervention programs aimed at optimizing both cognitive and socio-emotional development of children from low-SES backgrounds. Any improvements in academic performance, reduction in grade repeating and/or school failure are considerable steps forward in influencing both social and economic outcomes of children who grow up in circumstances which do not readily afford them sufficiently appropriate developmental opportunities. In addition, it is clear that such programs can be rich sources of empirical data concerning the mediating effects of cognitive and behavioral training on the structure and functioning of the brain, constituting from the eDCN perspective, valuable information on experience-dependent neuroplasticity.

Finally, we are optimistic about the role that cognitive neuroscience can play in the solution of the problem of the relationship between brain development and SES disparities. Ultimately, such a solution must include an explanation of how different social and economic conditions in which children grow up differentially influence the growth and development of neural mechanisms, and how such differences translate into adult neurocognitive outcomes. At a more practical level, cognitive neuroscience in collaboration with other disciplines can greatly contribute to the design of practical methods to deal with various developmental issues associated with different SES contexts. Both, the field's current and future technological and methodological advances are promising in addressing these questions. But probably those alone will not be enough. Substantial advances need to occur most and foremost at the level of theoretical conceptualization and underlying epistemology. The analysis and proposals reviewed here may contribute to a debate steering the field a step forward in the right direction.

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Socio-economic factors related to moral reasoning in childhood and adolescence: the missing link between brain and behavior

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Neuroscientific and psychological research on moral development has until now developed independently, referring to distinct theoretical models, contents, and methods. In particular, the influence of socio-economic and cultural factors on morality has been broadly investigated by psychologists but as yet has not been investigated by neuroscientists. The value of bridging these two areas both theoretically and methodologically has, however, been suggested. This study aims at providing a first connection between neuroscientific and psychological literature on morality by investigating whether socio-economic dimensions, i.e., living socio-geographic/economic area, immigrant status and socio-economic status (SES), affect moral reasoning as operationalized in moral domain theory (a seminal approach in psychological studies on morality) and in Greene et al. (2001) perspective (one of the main approaches in neuroethics research). Participants were 81 primary school (M = 8.98 years; SD = 0.39), 72 middle school (M = 12.14 years; SD = 0.61), and 73 high school (M = 15.10 years; SD = 0.38) students from rural and urban areas. Participants' immigrant status (native vs. immigrant) and family SES level were recorded. Moral reasoning was assessed by means of a series of personal and impersonal dilemmas based on Greene et al. (2001) neuroimaging experiment and a series of moral and socio-conventional rule dilemmas based on the moral domain theory. Living socio-geographic/economic area, immigrant status and SES mainly affected evaluations of moral and, to a higher extent, socio-conventional dilemmas, but had no impact on judgment of personal and impersonal dilemmas. Results are mainly discussed from the angle of possible theoretical links and suggestions emerging for studies on moral reasoning in the frameworks of neuroscience and psychology.

Keywords: moral reasoning, socio-economic factors, neuroscience, psychological research, moral domain theory

INTRODUCTION

Since the 1990s research on neuroscience has devoted increasing attention to brain processes involved in moral judgments and behaviors by investigating the biological foundations of moral reasoning. In such studies, moral dilemmas, visual sentences, and pictures were used as prompts of moral reasoning and emotions during the scanning of brain activity by functional Magnetic Resonance Imaging (fMRI) and in experiments using non-invasive brain stimulation techniques (e.g., Greene et al., 2001; Koenigs et al., 2009). These methods allowed investigators to identify the brain structures—in particular, the prefrontal and cingulated cortex—which play a role in moral thinking and behavior [for a recent review, see Fumagalli and Priori (2012)]. Starting with the seminal approach devised by Greene et al. (2001), a distinction between two possible brain systems supporting morality has been recurrently proposed. In Greene et al. (2001) experiment, one of the first attempts to identify the neural counterparts of moral judgment that is often quoted in the literature about neuroethics, a series of paired personal and impersonal moral dilemmas were used. The most famous situation described in such dilemmas is the trolley problem, in which the distinction between impersonal and personal dilemmas emerges clearly. The *impersonal* version of the trolley problem (switch dilemma) describes a runaway trolley which is heading for five people who will be killed if it proceeds on its present course. The only way to save them is to hit a switch that will divert the trolley to an alternative track so it will kill one person instead of five. Most people agree that it is right to divert the trolley in order to save five people at the expense of one. In the *personal* version (footbridge dilemma) a trolley threatens to kill five people. You are standing next to a large stranger on a footbridge that spans the tracks, in between the oncoming trolley and the five people. The only way to save the five people is to push this stranger off the bridge onto the track below. He will die if you do this, but his large body will stop the trolley from reaching the others. Most people claim that in this situation engineering the death of that man in order to save the five workers is immoral. In both situations the choice is between five people being killed or one person being killed. Why is the moral choice different in the two scenarios? According to Greene et al. (2001, p. 2106) "the crucial difference between the switch dilemma and the footbridge dilemma lies in the latter's tendency to engage people's emotions in a way that the former does not." This conclusion was supported by recording participants' brain activity scanned through fMRI. The basic finding was a correlation between the personal vs. impersonal features of the dilemmas and patterns of neural activity in emotion-related brain areas: personal moral dilemmas tended to activate emotion-related cerebral areas to a higher extent than impersonal dilemmas did; by contrast, the activation of brain areas associated with cognitive functioning was higher in impersonal than personal dilemmas.

Building on Greene et al. (2001) paper, the involvement of emotion in moral judgments has been stressed by successive investigations which identified specific neural correlates of reactions and decisions concerning moral issues which are emotionally charged (e.g., Moll et al., 2002; Harenski et al., 2008; Fumagalli et al., 2010). This supported the notion that in moral judgment and behavior two brain networks are involved, each associated with a distinctive attitude or form of processing: cognitive vs. emotional, reasoning-based vs. intuition-based, and explicit vs. implicit (Haidt and Joseph, 2004; Huebner et al., 2008; Moll and Schulkin, 2009; Bennis et al., 2010).

Identification of specific neuronal structures that contribute to moral reasoning and behavior strengthened the hypothesis of some innate neurobiological roots of morality (e.g., Haidt, 2001; Hauser, 2006), that could even explain the possible universal facets of moral reasoning. In this vein, in psychological research on morality and its development one of the most prominent theories is the moral domain theory (e.g., Turiel, 1983). According to this approach, moral knowledge is built and organized in separate domains which are related to different kinds of rules: *moral rules*, which are aimed at preserving the other's physical, psychological and social well-being (e.g., the rule forbidding kicking or hitting a classmate), and *socio-conventional rules*, which are set by authorities to better coordinate social interpersonal relationships in the social systems in which they are located (e.g., the school rule on calling the teachers by their first name). In reason of their own nature, moral norms are perceived by people as worthy by themselves and universally valid, independently of authorities' dictates and capacity to punish transgressors. On the other hand, by reason of their social purpose, socio-conventional rules are usually conceived to be closely dependent on authorities' capacity to guarantee respect of the norms and to be valid only in societies and organizations where authorities establish rules. As regards rule transgressions, people usually evaluate as serious and do not accept the breaking of moral rules, because of their harmful consequences for other(s), whereas, they judge breach of socio-conventional rules, which has no consequences of harm or unfairness, as less serious and acceptable under some conditions, for instance when they happen outside the context in which the rule has been formally stated (Turiel, 1983; Smetana, 1988; Smetana and Braeges, 1990; Smetana et al., 1993).

The distinction between moral and socio-conventional transgressions may be grounded on a different activation of emotions, since in moral rule violations the person empathizes with the victim, but empathy is not elicited by socio-conventional transgressions (Churchland, 2011). In the perspective of domain theory, the situations described in the personal and impersonal dilemmas proposed by Greene et al. (2001) can be considered as specific instances of transgressions of the moral rule which forbids killing or harming another person, even if her/his sacrifice could be advantageous for others. Therefore, personal and impersonal dilemmas assess the domain of moral rules by establishing a distinction between moral rule transgressions which elicit strong emotional-empathic reactions and moral rule violations which are less emotionally-empathically connoted.

Several studies have also provided some evidence that children make judgments and classify actions in terms of the moral or Socio-conventional domains from a very young age (e.g., Smetana, 1984; Tisak and Turiel, 1988; Smetana and Braeges, 1990; Smetana et al., 1993; Zelazo et al., 1996; Caravita et al., 2009; Gasser and Keller, 2009). For instance, from the age of 3 years children are aware of the consequences of moral actions and they evaluate situations such as stealing or hitting without provocation as wrong because of their intrinsic unfairness (Helwig et al., 2001); 4-year-old children are also able to distinguish between basic moral and Socio-conventional events (Smetana, 1981; Smetana and Braeges, 1990).

The precocity of making distinctions in evaluating the seriousness of rule transgressions of different domains is somehow consistent with the hypothesis of certain innate foundations or precursors of moral reasoning, such as an intuitive sense of moral wrongness (Haidt, 2001). Nevertheless, some studies in the framework of moral domain theory also support the notion that the evaluations of rule transgressions, even moral-rule violations, can be affected by differences in socio-economic conditions and cultural background (Sachdeva et al., 2012).

As regards socio-economic factors, notwithstanding the conception of morality as potentially grounded in biological structures and innate components, some neuroscientific studies have also provided evidence that neuronal structures and networks can be influenced by socio-economic dimensions. Variation in socio-economic status (SES) levels have been found to be associated with variation in brain serotonergic responsivity, and therefore, may also be related to differences in the prevalence of diseases and problematic behaviors, including aggression (Manuck et al., 2005). Gianaros and Manuck (2010) reviewed several studies, finding that indicators of socio-economic position (SEP) are connected with the functionality of monoamine neurotransmitter systems and to the activity and morphology of brain circuitries that are also involved in risk of health conditions. In an fMRI study (Lane et al., 2009), people reporting lower levels of subjective SEP displayed a reduced volume of gray matter in the rostral area of the anterior cingulate cortex. This area is implicated in the regulation of emotions and in organizing both physiological and behavioral reactivity to psycho-social stressors. Poverty status is also associated with individual neuro-cognitive performance in language, executive functions and memory in children and adolescents [e.g., Farah et al., 2004; Noble et al., 2005; for a review, see Farah et al. (2007)], suggesting that lower SES levels are connected with variation in the activity of some areas of the prefrontal cortex. In a research project on reading abilities, Noble et al. (2006) found that SES systematically modulated the associations between reading-related brain activities in the perisylvian and left fusiform areas and the phonological language skills of children with equivalent phonological skills. Altogether, this literature supports the hypothesis that socio-economic conditions may affect the function, and perhaps the development, of at least some of the brain areas and structures associated with emotion and cognition.

Moving from neuroscience to psychological researching on moral development, socio-economic factors have been found to affect moral values and moral processes of evaluating situations and taking behavioral decisions [for a recent review, see Sachdeva et al. (2012)]. For instance, the economic background of individuals helps to define the worth that is attributed to values or rules. The process is particularly evident for rules conceivable as socio-conventional. Haidt et al. (1993) carried out a study on the perception of moral violations that included (1) transgressions of rules preserving the other's well-being (i.e., moral rules, according to the moral domain framework) and (2) disrespect situations that were not harmful to others but involved the infringement of socio-conventional rules, such as using the national flag to clean the toilet. People of low SES evaluated the latter kind of situations as morally wrong more than did high-SES people, who were more likely to consider those behaviors as socially inappropriate and not as moral violations. In accordance with these findings, values and evaluations of what is moral seem to vary according to the differences in the social position of individuals, even those belonging to the same cultural context or country: for instance, the Indian social system of castes that are characterized by different standards in the conceptualization of what is morally right or wrong [for a review, see Sachdeva et al. (2012)].

Besides socio-economic factors, even cultural aspects can modulate moral reasoning. For instance, the identity of the person who is damaged by a behavior and of the agent of that behavior can define the moral acceptability of the action in some cultures but not in others. In fact, in some populations of New Guinea harming or killing a member of the same clan may be not acceptable, but if the victim belongs to a rival clan it becomes a moral obligation (Read, 1955). Among studies using the trolley problem paradigm or similar scenarios, Uhlmann et al. (2009) found that the evaluation of the sacrifice of the innocent victim as acceptable varied according to the identity of the victim (e.g., Iraqis vs. American civilians). In the same vein, Sachdeva et al. (2012) reported findings from a still unpublished study showing that Indian university students accepted the harmful action in the footbridge problem more readily when the agent was described as a member of the warrior caste than as a component of the priestly or scholarly caste. In the light of their own research data, Sachdeva et al. (2012) also suggested that, for components of cultures that are group- or duty-based, the distinction between the personal and impersonal versions of the trolley dilemma may be not as salient as for people belonging to individual- or rights-based cultural systems.

Cultural differences are mirrored in immigrant populations. Studies on morality and immigrant families have found some evidence that in child-rearing practices immigrants give emphasis to adopting the values of the host culture while maintaining the values of their own cultural heritage (Liu, 2009). Accordingly, immigrant parents modify children's school-related literacy activities to reflect their existing cultural beliefs and practices, including moral teaching (Perry et al., 2008). Therefore, in building their social identity immigrants refer to models from the host society but also attribute relevance to their cultural origins for moral dimensions.

In a tighter perspective, even living in urban or rural areas, that is, different socio-geographic/economic areas with related differences in density of the population, in economic activities, in socio-economic opportunities and infra-structures (e.g., OECD, 1994; EC, 2005; UNECE, FAO, OECD, and World Bank, 2005; Marcellini et al., 2007), has been found to have some influence on moral values and reasoning (e.g., Yagnik and Teraiya, 1999). For instance, in a study on early adolescents, rural youngsters were found to be higher in moral reasoning than peers from urban areas (Sahoo, 1985). Another research project on 10–28-year-olds, however, showed that people from villages tended to justify their moral decisions mainly in the norm-following and utilitarian modes, whereas, older urban youngsters showed a tendency to use deontological and perfectionistic justifications (Nisan and Kohlberg, 1982).

Given this background, investigating the impact of socio-economic, cultural and rural vs. urban characteristics of the living environment on morality appears to be a promising and important topic for neuroscientific research on moral reasoning. To our knowledge, however, no studies on neurobiology of morality have also included the investigation of differences in living socio-geographic/economic area, cultural, and economic conditions until now. Furthermore, most neuroscientific studies on morality involved adult healthy subjects and patients, whereas, only a very few studies have been realized on children and adolescents. (e.g., Eslinger et al., 2009) and we could not find any study that also considered possible differences between children/adolescents and adults in the brain counterparts of moral reasoning. The investigation of morality among children and adolescents represents, however, an important line of research in the psychology area (Kohlberg, 1981; Killen and Smetana, 2006). This framework highlights the necessity of examining features of moral reasoning and emotions in childhood and adolescence, not assuming the characteristics of morality in adulthood as a universal model of how morality works in children and adolescents.

Recently, overcoming the gap between neuroscientific studies and psychological studies on morality in childhood and adolescence has been proposed as a relevant challenge for future research (Killen and Smetana, 2008). Filling such a gap requires consideration of the differences in both theoretical background and content, as well as in methods. Consequently, we aimed to make a preliminary contribution towards bridging the gap between research on neurobiological foundations on morality and psychological research on morality by investigating whether and how certain socio-economic and cultural factors affect the moral reasoning of children and adolescents, as conceptualized and assessed in classical neuroscientific studies and in the moral domain theory. Furthermore, we aimed to test new tasks (Antonietti et al., 2012) which can be employed to assess moral reasoning because of their particular characteristics, in both neuroscientific and psychological research, so helping to construct a bridge between the two research fields.

In consideration of such purposes, we devised a research project aimed at investigating the influence of socio-geographic/economic area, cultural, and socio-economic factors on children's and adolescents' moral reasoning by assuming the theoretical background of the moral domain theory and the personal vs. impersonal distinction proposed by Greene et al. (2001) as conceptual frameworks.

First, we believe that personal and impersonal dilemmas used in neuroscientific research represent two kinds of transgression of moral rules: transgressions which imply direct contact with the victim vs. transgressions which imply indirect contact with the sacrificed person and that can be assumed to be less able to activate emotions. We expected that the transgression of moral rules would be judged as less acceptable than the infringement of socio-conventional rules and that the harmful actions described in personal dilemmas would be evaluated as more serious and less acceptable than the actions described in impersonal dilemmas, since personal dilemmas activate emotions to a higher degree than do impersonal dilemmas.

Second, we aimed at investigating whether certain socio-geographic/economic area related, cultural, and socio-economic factors affect not only the evaluations of acceptability of transgressions of socio-conventional vs. moral rules, but also the judgments of acceptability of the harmful actions as described in personal and impersonal dilemmas similar to those employed by Greene et al. (2001); in the literature, such dilemmas have never been considered in association with socio-economic and cultural dimensions. As far as moral and socio-conventional dilemmas are concerned, previous literature (see Sachdeva et al., 2012) showed that socio-economic factors are influential on evaluations of acceptability of transgressions of both moral and socio-conventional rules, but they are especially associated with variation in the evaluation of socio-conventional norm violations. Therefore, we expected that some differences would emerge in the evaluations of acceptability or rule transgressions because of differences in the socio-geographic/economic area in which participants lived, their immigrant status and their SES, and we conjectured that these dimensions were more influential for evaluations of socio-conventional rule infringements than for those of moral rule transgressions. As far as personal and impersonal dilemmas are concerned, because this is one of the first studies exploring how the evaluations of these kinds of situations can be affected by living socio-geographic/economic area, cultural, and socio-economic differences and the first one carried out on children and adolescents and in the Italian context, we were more speculative in terms of formulating our hypotheses. We mainly conjectured that the investigated factors were likely to be somehow influential on moral judgment, and in particular on impersonal dilemmas, that are less emotionally activating.

MATERIALS AND METHODS

PARTICIPANTS

Participants (**Table 1**) were 81 fourth-graders (M = 8.98 years; SD = 0.39), 72 seventh-graders (M = 12.14 years; SD = 0.61), and 73 tenth-graders (M = 15.10 years; SD = 0.38). In the Italian school system grade 4 is one of the two last grades of primary school, grade 7 is in middle school, and grade 10 is in high school. The three groups, equivalent for numbers of participants, were chosen so as to represent three different school levels (primary, middle, and high) of the Italian system. The same interval of 2 years separated the groups and the selected school grades prevented us interviewing students who were attending the first year of a school level (students attending the first year might not yet be accustomed to the new school level they were attending) but on the other hand we were prevented from recruiting students who were attending the last grade of the school level in which they were enrolled (students attending the last year are usually involved in preparation for formal or informal examinations which are often required in the last grade, and this, besides making teachers less available to take part in the research

Table 1 | Sample characteristics as percentages.

	Primary school (*n* = 81) Mean age: 8.98 years (SD 0.39)	**Middle school (*n* = 72) Mean age: 12.14 years (SD 0.61)**	**High school (*n* = 73) Mean age: 15.10 years (SD 0.38)**	**Total (*N* = 226)**
GENDER				
Boys	59.3	55.6	52.1	55.8
Girls	40.7	44.4	47.9	44.2
AREA				
Urban	46.9	48.6	52.1	49.1
Rural	53.1	51.4	47.9	50.9
IMMIGRANT STATUS				
Native	79.0	76.4	90.4	81.9
Immigrant	21.0	23.6	9.6	18.1
SES*				
Middle-low	27.2	27.8	6.8	20.8
Middle	54.3	65.3	48.0	55.8
Middle-high	16.1	6.9	45.2	22.5

*Note: *Two missing data in primary school.*

project, could interfere with the execution of the research tasks, for instance allowing researchers to test students at less favorable times in the school day).

Participants attended two primary schools, two middle schools, and two high schools in northern Italy. For each of the three school levels, one school was situated in the city of Milan and the other one in a small village or town in the province of Brescia. After Rome, Milan is the second largest city in Italy, with more than 1,324,000 inhabitants and a further 3,000,000 people who live in the metropolitan surrounds. The urban area of Milan is mainly industrial and is the most important industrial center in Italy. At the end of 2011, immigrants resident in the city of Milan numbered more than 217,300, i.e., 16.4% of all residents in Milan (Statistics of the City Hall of Milan, 2010). After Milan, in Lombardy the second biggest city is Brescia with around 193,800 inhabitants. The province of Brescia is very large and includes many small towns and villages, which are mainly characterized by rural and farm activities. Schools that were recruited in the area of Brescia were situated in a rural village (Borgo San Giacomo) and in a small rural town (Manerbio) in the province. Inhabitants of Borgo San Giacomo number about 5500, 17.6% of whom are immigrants. People resident in Manerbio number about 13,270, with around 1850 (14% of the population) immigrants living in the town.

In the participant sample, immigrants numbered 18.1%: they constituted 21% of the primary school pupils, 23.6% of the middle school students and 9.6% of the high school participants. Among immigrant participants, Asian children totaled 55.8%: 23.3% of immigrant students came from Africa, 11.6 % from other European countries, and 9.6% were from South America. When we considered the urban area of Milan and the rural area of Brescia separately, immigrant participants constituted 17.4% of students from the Milan area and 18.4% of the subsample from the Brescia area.

With regard to SES status (two missing data), 20.8% of participants' families were of low-middle SES, 55.8% of middle SES, and 22.5% of middle-high SES.

PROCEDURE

Before we allocated dilemmas (see next section), personal and impersonal dilemmas were mixed and then divided into two sequences so that the personal and impersonal versions of the same dilemma were not included in the same sequence. Even the moral and socio-conventional dilemmas were mixed and then organized in two sequences. In this way we obtained four sequences of dilemmas: sequences A, B of moral and socio-conventional dilemmas and sequences C, D of personal and impersonal dilemmas. The four sequences were then alternated and their order was reversed in order to obtain two administration protocols, in which sequences were ordered as follows: protocol 1 = sequences A, C, B, and D; protocol 2 = sequences D, B, C, and A. This strategy allowed us to start protocol 1 with one of the two sequences of moral and socio-conventional dilemmas, whereas, in protocol 2 the starting sequence was one of the two personal and impersonal dilemma sequences. Furthermore, the sequence of moral and socio-conventional dilemmas that was first presented in protocol 1 was presented second in protocol 2; the same happened for the two personal and impersonal dilemma sequences.

Each protocol was administered to half of the classes on each school level and area (i.e., urban vs. rural areas). Protocols were group-administered in the participants' classrooms during the school day in a single session of around 90 min per classroom. A research assistant supervised the protocol administration, explaining the goals of the study and how to fill in the dilemma protocol; she answered any question that was raised by participants. In primary school classes the research assistant also read aloud each of the dilemmas to give children the time to answer the dilemma question. A week after the protocol administration a make-up session was carried out to administer the protocol to students who were absent on the administration day. The study was authorized by the ethical committee of the IRCCS (Scientific Institute for Research, Hospitalization, and Health Care) "Eugenio Medea." Head-teachers and principals of schools and class committees of teachers allowed the participation of schools and classes in the study. Parents (or legal guardians) of children participating in the study were informed of the aims and procedure of the research project by means of a letter that was sent by schools and delivered in the classrooms by the teachers. In the letter parents were also informed that participation in the study was not mandatory and they were invited both to sign the consent form that was attached to the letter and to give back the signed form to the class teachers within 2 weeks if they consented to their children's participation in the study. In the letter the possibility to contact the researcher (whose mail and phone contact address were provided) in order to obtain more information was mentioned. All children of the involved classes obtained active consent for their participation in the study. At the beginning of the session, however, participants were also informed that their participation in the study was not obligatory, that it was not a curricular activity but an activity for purposes of research only, that they had the right to decide not to participate and that they could withdraw from the study at any time without any consequences. Then, before starting to fill in the measures they were requested to give oral consent to participation in the study and they were allowed to freely interrupt the administration at any time. Only five students (2.16% of pupils in the classes) decided not to participate in the study.

INSTRUMENTS

Personal vs. impersonal moral dilemmas

A series of eight pairs of dilemmas to be administered to primary school children and a corresponding series of dilemmas to be administered to older students were used (Antonietti et al., 2012). In both series the distinction between the personal and the impersonal versions is based on a unique, unequivocal criterion and possible confounding variables are discarded (Antonietti, 2011). Each dilemma has two parallel versions, so that a direct match between the personal and impersonal scenarios of each dilemma is possible, the contextual information being the same for each dilemma, apart from the aspect which specifically distinguishes between personal and impersonal versions. All dilemmas share the fact that the "helper," in order to produce a benefit to another child, has to operate so that harm, loss or disadvantage affects a third child/adolescent who is an innocent victim. In impersonal dilemmas the relationship with such a "victim" is indirect, namely, the helper does not interact face-to-face with the victim; in personal dilemmas the helper-victim relationship is direct, that is, the helper touches, looks at and/or speaks to the victim.

The formal features of the dilemmas are as follows: short text; easily understood; not involving knowledge of specific social norms; not describing dramatic and emotionally impressive situations. Furthermore, all dilemmas share the following "narrative" characteristics: They always and only involve children (as far as the moral aspect is concerned); the victim is always unaware (otherwise he/she might decide to sacrifice him/herself) and cannot avoid being involved in the action carried out by the helper; the helper cannot sacrifice her/himself instead of the victim; the action performed by the helper always has a certain outcome; the helper gains no direct advantage or suffers damage as a consequence of her/his action.

In order to insure equivalence and exclude other possible confounding variables, the impersonal and personal versions of each dilemma are similar with respect to the number of words, the number of contrastives (such as "but," "however," and "conversely," which might be influential since they stress the opposition between the two outcomes of the vignette), the degree of difficulty of the wording and of the syntactic structure, the degree of responsibility of the victim and of the beneficiary and the basic script (the helper may damage the victim to produce a benefit to the beneficiary).

The same basic structure of a pair of parallel dilemmas served for the series for primary school students and the corresponding series for older students (in the Italian school system middle and high schools share the same main characteristics). The differences between the versions devised for the two age levels rely on the kind of objects and situations mentioned in the dilemmas, in order to match what usually occurs in, respectively, children and adolescents' school and everyday experiences. In both the series, in half of the dilemmas characters are girls and in half boys. Examples of pairs of dilemmas are as follows:

> "Marco is hitting Giorgio very hard. You strike Marco with a football to stop him. Marco starts to cry and Giorgio succeeds in escaping."
>
> (*Primary school—Personal version*)

> "Nicola is hitting Luca very hard. You see that a football about to hit Nicola on the head and you don't warn him. Nicola is struck by the ball and starts to cry and Luca succeeds in escaping."
>
> (*Primary school—Impersonal version*)

> "Anna spreads rumors about Elisa and writes nasty things about Elisa in her own diary. You want Elisa to know what is happening. In front of Elisa you force Anna to give you her diary and read aloud what she has written about Elisa."
>
> (*Middle and High school—Personal version*)

> "Luisa spreads rumors about Caterina and writes nasty things about Caterina in her own diary. You want Caterina to know what is happening. You make Caterina find Luisa's diary and read what Luisa has written about her."
>
> (*Middle and High school—Impersonal version*)

Each dilemma ends with the question: "Is it right to do so?" The respondent has to check the box corresponding to the response "It is right" (coded as 1) or "It is wrong" (coded as 0) written below the text of the dilemma. Total scores of the sub-series of personal and impersonal dilemmas were the sum of the dilemma answers, with higher scores corresponding to admission of the damage to the innocent victim. In all school-level groups, reliability (Cronbach's alpha) of both the sub-series of personal and impersonal dilemmas was low but still acceptable, given the meaningful content of the measure and the small number of items (Schmitt, 1996). Reliability was better for middle school (personal dilemmas: $\alpha = 0.59$; impersonal dilemmas: $\alpha = 0.64$) and high school students (personal dilemmas: $\alpha = 0.57$; impersonal dilemmas: $\alpha = 0.64$) than for primary school children (personal dilemmas: $\alpha = 0.55$; impersonal dilemmas: $\alpha = 0.50$).

Moral vs. socio-conventional dilemmas

A series of 20 moral and a series of 20 socio-conventional dilemmas were created (Antonietti et al., 2012) to assess the perception of rules as breakable. Each item describes a situation in which a child is breaking a school rule that has been explicitly stated. In moral dilemmas the broken school rules are rules aimed at preserving the other's rights and psychological or physical well-being; in socio-conventional dilemmas the broken rules are designed to preserve the social order. Moral and socio-conventional dilemmas all involve only characters of the same age and of the same school-level of respondent. In both series, the child reading the situations assumes the perspective of the main character of the stories. In half of the dilemmas other characters are girls and in half boys. Dilemmas of the two series are equivalent in terms of the word number and grammatical structure. Sample dilemmas are as follows:

> "In your school there is a rule that you must not take other children's things. One day at school you are in the cafeteria and you force John to give you his lunch and you eat it in front of him."
>
> (*Primary school—Moral dilemma*)

> "In your school there is a rule that children must stand up when an adult enters the classroom. A morning a school janitress enters into the classroom and you don't stand up because you are aiming to draw."
>
> (*Primary school—Socio-conventional dilemma*)

> "In your school there is the rule forbidding damage to the belongings of others. One day at school during the break time you rip up the assignment of one of your classmates because she has obtained a better mark than you."
>
> (*Middle and High school—Moral dilemma*)

> "In your school there is a rule forbidding you to leave books outside personal lockers at the end of lessons. One morning, you are in a hurry to get out of school and you leave your history book on your desk."
>
> (*Middle and High school—Socio-conventional dilemma*)

For personal and impersonal dilemmas alike, each moral and socio-conventional dilemma is followed by a question asking whether the rule transgression is right (coded as 1) or wrong (coded as 0).

For both series of dilemmas the total score was obtained by summing the dilemma scores. The reliability of both series was acceptable among primary school children (moral dilemmas: $\alpha = 0.67$; socio-conventional dilemmas: $\alpha = 0.83$), good among both middle school (moral dilemmas: $\alpha = 0.91$; socio-conventional dilemmas: $\alpha = 0.92$), and high school students (moral dilemmas: $\alpha = 0.91$; socio-conventional dilemmas: $\alpha = 0.90$).

Immigrant status and SES

At the beginning of the anonymous protocol including the dilemma measures (see Procedure) participants were asked to answer eight demographic questions in order to assess gender, age in years, immigrant status (two questions), and family SES (four open-ended questions).

The two questions assessing participants' immigrant status consisted of a closed-ended question that requested participants to indicate whether they were *Italian* or *foreign*[1], i.e., non-Italian citizen, and an open-ended question asking for the name of their birth country if they were not Italian (i.e., "If you are foreign, please report your birth country").

The four open-ended questions assessing families' SES asked participants to report the job and qualifications of their father and mother. When one or both parents were dead or not living with their children, participants were asked to answer with reference to the adult care-givers who had legal responsibility for them. Based on statistical information on the average incomes of jobs provided by the Italian National Institute of Statistics, information on fathers' jobs and mothers' jobs was then classified in three categories of low-middle income, middle income, and middle-high income. Again, the two variables of fathers' and mothers' income levels were cross-referenced with each other and with the information on parental qualifications, in order to classify participants' families in SES categories. Although data on parental qualification were also considered, the allocation of families to SES categories was carried out by examining data on parental jobs. Data on parental qualifications provided supplementary information useful for better evaluation of the SES status of families but were not essential for assessing families' SES. We adopted this procedure because we were assessing the SES of participants, and not the socio-cultural level of their families, and in the literature (e.g., Pineo et al., 1977) SES is assessed with reference to parents' jobs. Following this procedure, we distinguished three SES categories of participants' families: families of low-middle SES level, that is, in which one or both parents did not have a job or had a job with low wages (and had only obtained a primary or middle school, that is, the obligatory school level in the Italian school system, qualification); families of middle SES level, based on at least one of the parents having a middle income level (and qualifications at least at high school level); families of middle-high SES level, whereby one or both the parents had a job with a high income (and in some cases an undergraduate degree; for families in this category, however, parents had high qualifications post-school).

[1]In the Italian cultural and linguistic context it is considered discriminatory to ask whether a person is an immigrant, whereas asking a person if she/he is "foreign" is considered neutral. This cultural specificity explains why in surveys realized in Italian contexts adults and children are usually asked to report whether they are "foreign," in comparison with "Italian," and not "immigrant."

RESULTS

STRATEGY OF ANALYSIS

Data were analyzed by Repeated Measures Analyses of Variance, with Student-Newman-Keuls post-hoc test. ANOVAs were computed by assuming the total scores in the series of, respectively, personal vs. impersonal and moral vs. socio-conventional dilemmas as dependent variables and the Kind of dilemma as within-subject factor, Gender as between-subject factor and, depending on the case, Area or Immigrant status or SES as third (between-subject) factor. The degrees of freedom vary in the analyses because of some missing data.

EFFECTS OF KIND OF DILEMMA AND GENDER

As far as the personal vs. impersonal dilemmas were concerned, in all ANOVAs (**Tables 2–4**) the effects of the Kind of dilemma were statistically significant, with lower scores in personal than impersonal dilemmas. Also, the effects of Gender were always statistically significant: girls obtained lower scores than boys (**Tables 2–4**).

With regard to moral vs. socio-conventional dilemmas, as reported in **Tables 2–4**, the main effect of the Kind of dilemma was significant in all the ANOVAs: scores were lower in moral than socio-conventional dilemmas. When we performed separate analyses in the three school-level groups[2], main effects of Kind of dilemma were similar to the findings obtained in the overall sample. As far as the personal vs. impersonal dilemmas were concerned, in all ANOVAs (not reported here to save space) the effects of the Kind of dilemma were statistically significant ($p_s < 0.05$): Scores were lower in personal than in impersonal dilemmas. With regard to moral vs. socio-conventional dilemmas, the main effect of the Kind of dilemma was significant in all three school levels analyzed separately ($p_s < 0.01$), with lower mean scores for the moral than for the socio-conventional dilemmas.

The main effect of Gender was marginal in the ANOVA including the Area as fixed factor, but significant in ANOVAs including Immigrant status and SES: girls scored lower than boys.

EFFECTS OF URBAN vs. RURAL AREA

Personal vs. impersonal dilemmas

Area (**Table 2**) did not significantly influence responses and all interaction effects were non-significant (**Table 3**).

Moral vs. socio-conventional dilemmas

Scores differed significantly across the areas, with the lowest mean scores for youngsters living in the rural area in comparison with peers living in the urban area (**Table 2**). The size of the effect for Area was not very high, however. None of the interaction effects was significant (**Table 3**).

[2]The ANOVAs which were performed separately for the three school-level groups confirmed that the school-level did not moderate the associations between the investigated variables, thus, these analyses were not further considered.

Table 2 | Mean scores (and standard deviations) of personal vs. impersonal and moral vs. socio-conventional dilemmas in ANOVA including area as fixed factor.

Group	Personal dilemmas	Impersonal dilemmas	Moral dilemmas	Socio-conventional dilemmas
Urban area	1.88 (1.47)	2.56 (1.89)	2.23 (3.69)	4.92 (4.97)
Boys	2.24 (1.41)	2.85 (1.87)	2.88 (4.14)	5.46 (5.16)
Girls	1.33 (1.41)	2.12 (1.85)	1.28 (2.67)	4.15 (4.63)
Rural area	1.71 (1.54)	2.38 (1.61)	1.12 (2.52)	3.45 (4.62)
Boys	1.81 (1.53)	2.61 (1.63)	1.35 (2.35)	3.60 (4.72)
Girls	1.60 (1.55)	2.12 (1.55)	0.87 (2.69)	3.30 (4.56)
Total	1.79 (1.50)	2.47 (1.75)	1.68 (3.21)	4.20 (4.86)
Boys	2.03 (1.48)	2.74 (1.76)	2.18 (3.51)	4.61 (5.03)
Girls	1.48 (1.49)	2.12 (1.68)	1.06 (2.67)	3.70 (4.59)

Table 3 | Summary of ANOVA for personal vs. impersonal and moral vs. socio-conventional dilemmas, including area as fixed factor.

	Personal vs. impersonal dilemmas			Moral vs. socio-conventional dilemmas		
	df	F	η^2	df	F	η^2
Kind of dilemmas	1, 207	44.19***	0.180	1, 221	123.54***	0.360
Area	1, 207	0.26	<0.001	1, 221	5.50*	0.024
Gender	1, 207	8.67**	0.040	1, 221	3.47†	0.015
Kind of dilemmas × area	1, 207	0.03	<0.001	1, 221	0.71	0.003
Kind of dilemmas × gender	1, 207	0.08	<0.001	1, 221	0.29	0.001
Area × gender	1, 207	1.40	0.010	1, 221	1.16	0.005
Kind of dilemmas × area × gender	1, 207	1.26	0.010	1, 221	0.02	0.001

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, †$p < 0.10$.

Table 4 | Mean scores (and standard deviations) of personal vs. impersonal dilemmas and moral vs. socio-conventional dilemmas in ANOVA including immigrant status as fixed factor.

Group	Personal dilemmas	Impersonal dilemmas	Moral dilemmas	Socio-conventional dilemmas
Native	1.84 (1.53)	2.54 (1.73)	1.55 (3.01)	4.29 (4.97)
Boys	2.08 (1.53)	2.85 (1.72)	2.01 (3.28)	4.61 (5.15)
Girls	1.54 (1.49)	2.15 (1.67)	0.98 (2.55)	3.92 (4.73)
Immigrant	1.57 (1.37)	2.14 (1.84)	2.32 (3.98)	3.77 (4.29)
Boys	1.83 (1.27)	2.26 (1.89)	2.96 (4.40)	4.61 (4.54)
Girls	1.14 (1.46)	1.93 (1.82)	1.47 (3.26)	2.65 (3.77)
Total	1.79 (1.50)	2.47 (1.75)	1.68 (3.21)	4.20 (4.85)
Boys	2.03 (1.49)	2.74 (1.76)	2.18 (3.51)	4.61 (5.03)
Girls	1.48 (1.49)	2.12 (1.68)	1.06 (2.67)	3.70 (4.59)

EFFECTS OF IMMIGRANT STATUS

Personal vs. impersonal dilemmas

Being Italian or an immigrant (**Table 4**) failed to affect responses significantly and the native vs. immigrant status did not interact significantly with the other variables (**Table 5**).

Moral vs. socio-conventional dilemmas

The interaction effect of Kind of dilemma × Immigrant status was significant (**Table 5**). Both Italians' and immigrants' scores were lower in moral than in socio-conventional dilemmas, but immigrants obtained scores concerning moral rules slightly higher than Italians, whereas, Italian students scored higher than non-Italian pupils in socio-conventional dilemmas (**Table 4**). Other main and interaction effects were not significant (**Table 5**).

EFFECTS OF SES

Personal vs. impersonal dilemmas

With regard to personal and impersonal dilemmas (**Table 6**), neither main effects of SES nor interaction effects were significant (**Table 7**).

Moral vs. socio-conventional dilemmas

When SES level was introduced into the model as fixed factor (**Table 6**), the interaction effect of the Kind of dilemma by SES

Table 5 | Summary of ANOVA for personal vs. impersonal and moral vs. socio-conventional dilemmas, including immigrant status as fixed factor.

	Personal vs. impersonal dilemmas			Moral vs. socio-conventional dilemmas		
	df	F	η^2	df	F	η^2
Kind of dilemmas	1, 207	22.66***	0.100	1, 221	50.22***	0.185
Immigrant status	1, 207	1.92	0.010	1, 221	0.01	<0.001
Gender	1, 207	4.52*	0.020	1, 221	3.86*	0.020
Kind of dilemmas × immigrant status	1, 207	0.09	<0.001	1, 221	5.27*	0.023
Kind of dilemmas × gender	1, 207	0.13	0.001	1, 221	0.01	<0.001
Immigrant status × gender	1, 207	0.05	<0.001	1, 221	0.43	0.002
Kind of dilemmas × immigrant status × gender	1, 207	0.86	0.004	1, 221	0.45	0.002

Note: *$p < 0.05$, ***$p < 0.001$.

Table 6 | Mean scores (and standard deviations) of personal vs. impersonal dilemmas and moral vs. socio-conventional dilemmas in ANOVA including SES as fixed factor.

Group	Personal dilemmas	Impersonal dilemmas	Moral dilemmas	Socio-conventional dilemmas
Medium-low	1.62 (1.55)	2.55 (1.74)	1.37 (2.57)	2.65 (3.20)
Boys	2.00 (1.71)	3.00 (1.78)	2.04 (3.29)	3.35 (3.75)
Girls	1.16 (1.21)	2.00 (1.56)	0.69 (1.29)	1.96 (2.42)
Medium	1.78 (1.49)	2.54 (1.79)	1.95 (3.72)	4.50 (5.21)
Boys	1.92 (1.42)	2.76 (1.79)	2.37 (3.91)	4.66 (5.18)
Girls	1.60 (1.56)	2.26 (1.77)	1.42 (3.43)	4.29 (5.30)
Medium-high	1.92 (1.49)	2.17 (1.65)	1.37 (2.25)	5.02 (4.95)
Boys	2.25 (1.38)	2.39 (1.69)	2.00 (2.72)	5.76 (5.49)
Girls	1.45 (1.54)	1.85 (1.60)	0.55 (0.96)	4.04 (4.06)
Total	1.78 (1.49)	2.45 (1.75)	1.70 (3.22)	4.24 (4.86)
Boys	2.02 (1.46)	2.72 (1.76)	2.22 (3.53)	4.67 (5.04)
Girls	1.48 (1.49)	2.12 (1.68)	1.06 (2.67)	3.70 (4.59)

Table 7 | Summary of ANOVA for personal vs. impersonal and moral vs. socio-conventional dilemmas, including SES as fixed factor.

	Personal vs. impersonal dilemmas			Moral vs. socio-conventional dilemmas		
	df	F	η^2	Df	F	η^2
Kind of dilemmas	1, 203	32.47***	0.138	1, 217	102.51***	0.321
SES	1, 203	0.21	0.002	1, 217	1.73	0.020
Gender	1, 203	9.00**	0.042	1, 217	4.71*	0.021
Kind of dilemmas × SES	1, 203	2.50†	0.024	1, 217	6.01**	0.052
Kind of dilemmas × gender	1, 203	0.01	<0.001	1, 217	0.03	0.001
SES × gender	1, 203	0.53	0.005	1, 217	0.34	0.003
Kind of dilemmas × SES × gender	1, 203	0.38	0.004	1, 217	0.34	0.003

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, †$p < 0.10$.

was significant (**Table 7**). When we computed follow-up ANOVAs separately for mean scores of moral and socio-conventional dilemmas, pupils of different SES levels did not significantly differ in scores of moral dilemmas, whereas, for the socio-conventional dilemmas children from families with middle-low SES had significantly [$F_{(2,\ 217)} = 3.12$, $p < 0.05$, $\eta^2 = 0.030$] lower scores than peers of middle and middle-high SES. Furthermore, participants with middle-low SES were the ones with the smallest difference between scores for the two types of dilemmas. The difference between scores of moral and socio-conventional dilemmas was significant ($p < 0.001$) in all three SES-level groups, with lower scores for moral dilemmas than for socio-conventional dilemmas. Other main and interaction effects were not significant (**Table 7**).

DISCUSSION AND CONCLUSIONS

First of all it is worth noting that the sets of moral dilemmas we devised appeared to be valid overall since the patterns of responses which we recorded were consistent with the underlying theoretical grounds and the literature. As far as personal vs. impersonal dilemmas were concerned, the reluctance to evaluate as acceptable helping an individual by damaging another one was higher if there was a direct contact between the agent and the victim, as compared with situations in which the agent and the victim did not interact directly. As regards the moral type of dilemma compared with the socio-conventional one, the transgression of moral rules was evaluated as less acceptable more often than for socio-conventional rules.

Boys obtained higher scores in the dilemmas than girls, suggesting that girls accepted breaking rules and harming a victim to a lower degree than boys. Literature did not systematically support the notion that boys and girls differ in applying moral criteria to situations or using moral reasoning [for a review, see Killen and Smetana (2006)]. The trends we found in favor of a greater acceptance of rule transgressions and harming actions by boys than girls, however, agrees with the literature on gender differences related to social behaviors, showing that in childhood and adolescence boys are usually more openly aggressive than girls and more inclined to accept aggressive actions (e.g., Rose and Rudolph, 2006) and to self-justify their own violations of moral values (e.g., Hymel et al., 2010).

Moving to the main topic of the paper, in accordance with our hypotheses socio-economic, cultural, and socio-geographic/economic area factors affected the two sets of dilemmas differently. Specifically, all the investigated variables failed overall to affect moral judgments in the personal vs. impersonal dilemmas. Responses in moral and socio-conventional dilemmas, however, were affected by these variables. In particular, children and adolescents in rural areas perceived rules as less breakable than urban peers did and the difference between youngsters living in these two areas was higher for socio-conventional rules than moral rules. Immigrant status significantly interacted with the kind of dilemmas supporting the distinction between moral and socio-conventional tasks: whereas, the native children considered moral rules less breakable than immigrants, the opposite was true for the socio-conventional rules. Such a distinction was stressed also by the effects of SES: whereas, such variables failed to affect moral dilemmas, it appeared that the transgression of socio-conventional rules was judged as acceptable more often by students belonging to families with a middle-high SES status than by students belonging to middle-low SES families.

Overall, the data clearly showed that the investigated socio-economic and cultural differences affected moral evaluations of the transgressions for moral and socio-conventional dilemmas.

EFFECTS OF SOCIO-GEOGRAPHIC/ECONOMIC AREA, CULTURAL, AND SOCIO-ECONOMIC DIMENSIONS ON MORAL REASONING

When we considered our findings in detail, clear evidence emerged that contextual factors can affect at least some kinds of moral reasoning, thus stressing the need to include these dimensions in the investigation of morality even in neuroscience. We found that children and adolescents living in rural areas considered both moral and socio-conventional norms as breakable to a lesser extent than peers living in an urban area. This finding is in line with literature providing evidence that youngsters living in rural areas tend to justify their moral decisions mainly in the norm-following (Nisan and Kohlberg, 1982). This result may express the higher level of social control characterizing small communities like those in the rural area that we investigated. In small towns and villages the compulsoriness of norms can be felt to a higher degree because all the community members contribute to guarantee the respect of the rules (Haidt et al., 2003).

A more complex pattern of results emerged with reference to the immigrant status of participants, as native youngsters considered moral rules breakable to a lesser degree than immigrants, but immigrants accepted the transgressions of socio-conventional rules to a lesser degree than native peers. This finding extends our knowledge of the psychological profiles of immigrant young people (Arredondo-Dowd, 1981). A plausible explanation is that people who have been living since the birth in a country realize, thanks to the knowledge they have acquired of the local or national "history" of some norms, that socio-conventional rules are set and then modified or removed as a consequence of negotiation, and thus they are more aware than immigrants, who do not share the same kind of knowledge, of the non-absolute nature of such rules. An alternative explanation makes reference to the association between social experience and perceived control (Lachman and Weaver, 1998). Since, the environment where immigrants live may be less familiar to them than to native peers, they can perceive a reduced sense of control over such an environment, and this might lead them to perceive it (including the social norms which are part of it) as less modifiable (and thus the social norms as less breakable). However, both explanations are valid for immigrants that have not been living in the host country since a very long time, and that cannot have acquired the same experience of the local culture as the native people.

It worth noting, however, that in general immigrants differentiated less between moral and socio-conventional norms. We have to remember that in our analyses children from different countries of origin and cultural backgrounds were included in the immigrant group (the small numbers of participants belonging to each separate country sub-group prevented us from testing for possible differences among cultures). Thus, we cannot exclude the possibility that the difference in evaluating norms we found is owed not to cultural specificities but to an in-group/out-group effect. That is, it is possible that immigrants feel to a greater extent that all the rules of the host society in which they live need to be respected to the same degree, independently of distinctions between norms.

As far as SES is concerned, children of families of middle-low SES judged socio-conventional rule transgressions as less acceptable than peers whose families had middle and middle-high SES statuses. This outcome is in accordance with findings reported by Haidt et al. (1993) showing that low-SES people considered disrespectful and disobedient actions that were not harmful to others as moral violations. It seems that children and adults of lower levels of SES are less able to perceive the conventionality of rules regulating social behaviors which do not imply injury or personal damage. This may express some differences in the socio-cultural levels of families and of the contexts in which people live and grow up, namely, differences which are tightly bound up with variations in socio-economic conditions. Since, the environment where low-SES children and adolescents live exposes them to less rich sets of experiences, and thus they have fewer opportunities to differentiate among them (Evans, 2004), we have reason to maintain that such reduced differentiation might also apply to behavioral rules. A further explanation, which can be also applied to the difference between native and immigrant persons, refers to possible discrimination effects associated to the status: Children and adolescents belonging to low SES families, as well as immigrants, may be more rigid in conceiving rules because they know or believe that the consequences from infringing them might be heavier—for instance, in terms of social exclusion—for them than the consequences for an individual of a high SES family (or a native person) breaking the same rule (Phinney et al., 1998; Liebkind and Jasinskaja-Lahti, 2000; Calavita, 2007; Brown, 2011).

NEUROSCIENTIFIC AND PSYCHOLOGICAL RESEARCH ON MORAL REASONING: BRIDGING THE THEORIES AND THE METHODS

This study is among the first to investigate sensitivity to the distinction between personal vs. impersonal dilemmas among children and adolescents. In accordance with findings provided in the literature on adults, even children and adolescents (as overall sample and separate school-level groups) evaluated actions which harmed an innocent victim for a prosocial purpose as less acceptable when the agent directly interacted with the harmed person than when the contact between the agent and the victim was indirect. This outcome supports the notion that children and adolescents are sensitive, as well as adults, to personal and impersonal distinction. Similarly, Pellizzoni et al. (2010) found that, when administered the simple versions of the switch and the footbridge dilemmas, even the majority of children aged 3–5 years judged the sacrifice of an innocent victim as acceptable when there was no physical contact with the victim and this action was intended to produce the greatest good for the greatest number of people. Along with this result for children of such a young age, our findings on the evaluation of dilemmas by children from primary to high school indicate that the distinction between personal and impersonal persists across different ages.

Similarly to what happened with regard to the personal and the impersonal dilemmas, the distinction between moral and socio-conventional dilemmas was consistent in the overall sample and across the school-level groups: Transgressions of moral rules were evaluated as less acceptable than violations of socio-conventional rules whose purpose was not to preserve others but to guarantee the order of social organization. The similarity of findings on the distinction among personal and impersonal and the distinction among moral and socio-conventional is consistent with the hypothesis of an overlap between the organization of morality as conceptualized in neuroethical studies such as that by Greene et al. (2001) and as conceived in the moral domain theory (Nichols, 2002, 2004). We can speculate that emotions can provide the links between the two theoretical perspectives. Both personal dilemmas and moral dilemmas are likely to activate to a greater extent empathic feelings towards the person who suffers as a result of the agent's action. In situations such as those described in impersonal dilemmas the physical distance between the agent and the victim, which ensues from the indirect contact, does not elicit emotions and empathic responses at the same rate as situations of personal dilemmas. Even more than impersonal dilemmas, the actions represented in socio-conventional dilemmas are likely not to generate empathic emotions, because they are behaviors infringing rules which forbid violations of social conventions without harmful consequences. Therefore, emotions and empathy may underlie differences in moral reasoning and the higher rate of empathy elicited by moral rule transgressions and actions that directly hurt another person may explain the reasons for which at any age (e.g., Smetana and Braeges, 1990; Pellizzoni et al., 2010) these situations are judged to be more serious than socio-conventional rule violations and indirect harmful behaviors, respectively.

The findings about the effects of socio-economic factors on moral evaluations help to complete this picture. Differences in socio-economic and cultural conditions have been found not to affect evaluations of the seriousness of the actions described in personal dilemmas as compared with impersonal dilemmas. On the contrary, socio-economic factors mainly influenced the judgments on infringements of socio-conventional rules, which were considered as more acceptable than moral rule violations. In general, breaking moral rules was scarcely accepted. This pattern of findings supports our hypothesis that personal and impersonal dilemmas may describe two categories of transgressions of the same moral norm which does not allow someone to harm another person. Variations in socio-economic and cultural factors are not influential on differences in moral evaluations of these dilemmas since they express two instances of the same kind of moral violation, which is generally little accepted.

Another novel finding of this study was that the expected higher rates of transgression in the socio-conventional dilemmas in comparison with moral ones emerged in children and adolescents through scenarios that were shorter than those used in traditional research and in which the situation was sketched in a few sentences. These features of the dilemmas we used allow investigators to apply them in research projects realized by means of the fMRI technique, thus making possible studies of moral reasoning as conceptualized by the moral domain theory in the neuroscience framework. This is another possible link between neuroscientific and psychological research on morality. It is worth noting that, even though the structure of Greene et al. (2001) dilemmas and of the dilemmas we used was almost the same, the tasks employed in the present study did not concern, as Greene et al. (2001) dilemmas did, odd situations such as the trolley problem but rather everyday situations. It has been argued that the dilemmas often used in neuroethics investigation concern unusual situations and this is seen as a limitation (Nichols and Mallon, 2006; Klein, 2011). The dilemmas we employed did not share such a limitation, and thus they might be considered for future research.

Besides the links between the neuroethical and psychological perspectives which can be identified at the methodological level, other relationships can be found at the theoretical level. Both perspectives are aimed at discovering the different "signatures" supporting morality (Kelly et al., 2007). In addition, in both paradigms the existence of dual systems has been maintained. Finally, in both perspectives one of the two systems is perceived as closely associated with emotion (Teper et al., 2011). Thus, a series of fundamental similarities (despite obvious differences) can help to construct bridges between the two paradigms. Such bridges can be established thanks to bi-directional relationships. On the one hand, the psychological perspective can propose new conceptual distinctions (such as the distinction between moral vs. socio-conventional rules), show the role played by socio-economic and socio-cultural factors in modulating the corresponding differences, and stress the need for neuroscientific research to detect possible cerebral counterparts. On the other hand, neuroscientific investigations can suggest and support conceptual distinctions on the basis of the evidence of different underlying brain structures and processes. The common goal of discovering the natural grounds of morality might be achieved better thanks to the links between the two perspectives which can be highlighted by applying the same research materials and theoretical frameworks.

LIMITATIONS AND FUTURE DIRECTIONS

There are some limitations in this study. First, as mentioned before, because of the size of the samples, we could not distinguish in the group of immigrants between children and adolescents from different countries and, consequently, from specific different cultural backgrounds. In addition, the immigrant status as assessed on the basis of the place of birth and on being or not Italian is only an approximated measure of the actual differences in cultures shared by the individuals. These limitations made our interpretation of differences depending on immigrant status speculative to some extent.

Moreover, as regards measures, we have to bear in mind that reliability coefficients for the personal and impersonal dilemmas were low, particularly for the primary school subsample. This feature of the measure may be owed to its short length, but also to the complexity of the assessed construct, for which Greene and colleagues did not provide reliability. Nevertheless, the association we found needs to be cautiously interpreted, because it may be underestimated (Schmitt, 1996). Finally, the collective way in which dilemmas were administered, participants simply being asked to endorse either the "right" or "wrong" response, prevented us from acquiring information about the reasons underlying their responses.

Notwithstanding these limitations, this study was one of the first to provide some bridges between studies on morality in the framework of neuroscience and in the framework of psychological research. In particular, our findings on possible overlaps between the conceptualizations of moral reasoning that were provided by the moral domain theory and the personal vs. impersonal distinction suggest the value of continuing to explore this link between theories. Future studies might investigate the neural counterpart of the distinction between different moral domains, that is, the domains of moral and socio-conventional rules. Future research might also better analyze the possible involvement of emotions in differently evaluating transgressions of moral and socio-conventional norms, even in association with judging as acceptable the harmful action of an innocent victim in the frame of personal or impersonal situations. Even more remarkably, in this study socio-economic and cultural dimensions have been found to be influential on some kinds of moral reasoning. It agrees with the literature, providing evidence that moral knowledge and reasoning, as well as moral behavior (Jimerson et al., 2010), differ as a function of variations in cultures and socio-economic dimensions (Sachdeva et al., 2012). Until now, however, research concerning the neurobiological basis of morality has not considered the possible impact of cultural and economic variation on moral knowledge and behaviors. Nevertheless, a few studies [e.g., Farah et al., 2004; for a review, see Farah et al. (2007)] have started to show that differences in the socio-economic conditions of life are also associated with different activation of neural structures and even possible morphological differences in some areas (Lane et al., 2009). Can socio-economic and cultural factors also affect the neural counterparts of morality? If the answer to the question is positive, do these contextual factors affect differently the neuronal networks involved in the emotional and cognitive facets of morality? These are open issues for future investigation and suggest interesting routes for future research projects trying to fill the gap between distinct fields of study (Killen and Smetana, 2008).

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Socio-cultural effects on children's initiation of joint attention

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Exchanging gazes with a social partner in response to an event in the environment is considered an effective means to direct attention, share affective experiences, and highlight a target in the environment. This behavior appears during infancy and plays an important role in children's learning and in shaping their socio-emotional development. It has been suggested that cultural values of the community affect socio-emotional development through attentional dynamics of social reference (Rogoff et al., 1993). Maturational processes of brain-circuits have been found to mediate socio-cultural learning and the behavioral manifestation of cultural norms starting at preschool age (Nelson and Guyer, 2011). The aim of the current study was to investigate the relations between cultural ecology levels and children's joint attention (JA). Initiation of JA bids was studied empirically as a function of the level of social load of the target toy (3 levels), the community level of adherence to traditional values (3 levels), parental education (2 levels), and gender. Sixty-two kindergarten aged children were enrolled in a structured toy-exploration task, during which they were presented with toys of various social loads, with social agents (i.e., mother and experimenter) present nearby, and non-social distracters presented intermittently. Measurements included the child's number of JA bids and the extent of positive affect. Analysis of variance indicated that the child's initiation of JA toward the social partner was affected by all levels of cultural ecology (i.e., toy's social load, adherence to tradition values, parental education, gender), thus supporting the study's hypotheses. The effects were such that overall, children, particularly girls' JA initiation was augmented in social toys and moderated by the socio-cultural variables. These results suggest that cultural ecology is related to children's JA, thereby scaffolding initiation of social sharing cues between children and adults. JA plays a role in adjusting children's internal representations of their respective ecological environment.

Keywords: joint attention, cross-cultural differences, tradition, gender, affect, play, exploration, social

INTRODUCTION

The need to share attention and experience among individuals that interact with each other is an intrinsic social need that accompanies humans throughout their lifespan, so as to organize their social and emotional experiences (Trevarthen and Aitken, 2001; Hobson, 2002). The behavior of social referencing in the presence of a third object or event, coined as joint attention (JA), is usually intertwined with a behavior of solitary exploration and is known to be a basic form of communication (Mundy and Sigman, 2006; Mundy and Jarrold, 2010). This ability involves the initiation of JA; namely, directing the partner's attention to some aspect of one's experience and a response to such an initiation, primarily by gaze following (Scaife and Bruner, 1975; Mundy et al., 2007). The process of JA involves a continued monitoring of one another's attention, and the awareness that this attention is being monitored by a social agent (Tomasello, 1995). In order for an interaction to be considered as JA, the social agents must show awareness to both the object and the partner, as well as to the shared perception that characterizes the situation so that activities surrounding the object are coordinated (Tomasello, 2005).

The ability to coordinate attention toward a third object in a dyadic interaction appears in the first year of the child's life and continues to develop as the child grows (Moll and Tomasello, 2004). JA behaviors start to appear as early as 3 months of age and elaborate for the next 15 months (Tomasello, 2005; Mundy and Jarrold, 2010). These behaviors include the ability to follow a social partner's direction of attention, i.e., responding to JA, and to direct the partner's attention to a certain aspect of the environment with the intention of sharing the experience, i.e., initiation of JA or JA bids (Mundy and Acra, 2006). Several frameworks of JA view this behavior as a primary communication mechanism which serves as a pivotal building block in the development of social competence (Bretherton, 1991; Baldwin, 1995; Mundy, 1995, 2003; Tomasello, 1995; Dawson et al., 2001; Mundy and Neal, 2000; Brauer et al., 2005). According to these frameworks, the ability to jointly attend to an object serves as a basis for the sharing of information and the understanding of mutual meanings and intentions (Mundy and Jarrold, 2010). We would therefore like to suggest that JA may reflect an evolving representation of the other agent's mind, abilities, and cultural values.

JA is known to be one of the first steps toward understanding the concept that people are independent agents with individual thoughts, beliefs, intentions, and points of reference. The goal of JA is to share intentions—concrete at the beginning of the development, and more abstract later on (Mundy and Sigman, 2006). Thus, JA is seen as a precursor to the development of theory of mind—the ability to attribute mental states to self and others (Baron-Cohen, 1991; Tomasello, 1995; Charman et al., 2000). Indeed, current research shows a relation between JA and theory of mind (Moll and Tomasello, 2004), language development (Brooks and Meltzoff, 2005), and overall social competence at later developmental stages (Mundy and Sigman, 2006).

It is argued that as the child develops, the ability to coordinate attention becomes internalized and the capacity to socially coordinate mental attention with internal representations appears, thereby playing a central role in the development of social cognition (Mundy and Jarrold, 2010). As children develop, they acquire the ability to coordinate attention not only to overt aspects of the environment such as objects or people, but also to covert aspects such as ideas, intentions, and emotions (Tomasello, 1995; Adamson et al., 2004; Mundy and Sigman, 2006; Van-Hecke et al., 2007). We would like to suggest that this developmental process may also reflect internalizations of cultural values and community expectations.

It is long known that the individual development is a product of a complex interaction between personal characteristics and environmental contexts. Through the first several years of childhood, the child's cognizance of his culture evolves and manifests itself through his behavior and internal processes (Dunn, 1994). Thus, when assessing JA it seems essential to take into account the context of the interaction and the child's ecology (Cole and Bruner, 1971).

Societal foundations, which reflect, among other things, values, community type, and socio-economic resources, correlate with a variety of developmental, cognitive and socio-emotional outcomes (Zill et al., 1995; Lareau, 2003; Vigil et al., 2006; Bartkowski et al., 2008). Hence, it is plausible that the corner stone of social interaction, the parent–child interaction characteristics, would reflect these factors in some way. Rogoff's work pointed to the notion that adults and children from all cultures jointly structure their interaction and engage in social referencing, and underscored that social referencing reflects socio-cultural characteristics and cultural values (Rogoff, 1990). Specifically, an ethnographic research by Rogoff et al. (1993) pointed to the relation of socio-cultural variances to differences in JA characteristics, specifically noting culturally dependent differences in directing attention to non-verbal cues, such as shared gaze, changes in posture and affect to highlight a target object or event in the child's natural habitat (Rogoff et al., 2003).

Literature regarding intercultural differences in parent–child interactions emphasizes the role of transmission of cultural characteristics to children from the adult environment. It has been suggested that socio-cultural effects of JA may serve a particularly important role in the process of socio-emotional development since the ability to jointly attend and share experience in response to a culturally specific stimulus is thought of as a key arena for acquiring and integrating culture (Callaghan et al., 2011). We would like to suggest that JA may serve as an instrumental mechanism in these processes.

It has been recently suggested that as we develop, our sensitivity to socio-cultural variation and to contextual cues becomes apparent through the maturation of the ventral prefrontal cortex (VPFC) (Luna et al., 2001; Davidson et al., 2006). The VPFC is a brain region mediating the executive functions of valuation, inhibition and rule acquisition. As maturation processes occur, the child's sensitivity to context is enhanced, a process expressed by increased ability to exert inhibitory control, regulate orienting to targets in the environment (Harel et al., 2010; Geva et al., 2011), and express social rules adaptively (Nelson and Guyer, 2011). According to Nelson and Guyer (2011), these processes emerge at preschool age, advance markedly in middle childhood and continue to develop through adulthood. Thus, it seems that the enhanced ability to use socio-cultural rules in order to adaptively function in society is made possible by the interaction between internal long-term neuronal maturational processes and the exposure to socio-cultural stimuli in daily life. Moreover, maturational processes in the VPFC networks that emerge at preschool enable the child to express behaviorally their sensitivity to socio-cultural cues and ecological contexts.

Bronfenbrenner's classical ecological systems model (ESM, Bronfenbrenner, 1979) posits that children's development is affected by the various systems which surround them. This model's basic premise refers to five levels of context, concentrically organized around the child (1) the microsystem—the child's immediate environment; (2) the mesosystem—connections between microsystems or contexts; (3) the exosystem—wider factors with which the child has no direct contact, but nonetheless still impacts her/his life; (4) the macrosystem—the broad society to which the child belongs; (5) the chrono-system—changes and events over the life-course and socio-historical circumstances. Current research supports the notion proposed by the ESM (Odom et al., 2004; Jordan, 2005; Stacks, 2005). These lines of work show that factors from different ecological levels join together in scaffolding various personal characteristics and mechanisms, such as at the macrosystem level of ethnicity (Lewis et al., 2010), the exosystem level of religiosity (Bartkowski et al., 2008) and social-class (Hart and Risley, 1995; Lareau, 2003; Farkas, 2004), and the mesosystem and microsystem levels of familial construct (Perner et al., 1994).

Adherence to different cultural values may account for interpersonal differences in a variety of children's individual measures at various levels of the ESM. For example, in Asian societies, children who are shy and reticent are high on well-being measures as opposed to their Western counterparts, since these behaviors match the collective values of the Asian culture (Chen, 2000). At the intermediate ecological level, it was shown that adherence to religious values moderates the relation between familial conflict and children's pathological outcomes (Davis and Epkins, 2009).

Parent–child interactions and specifically JA are usually explored through the prisms of either the microsystem or the macrosystem. Our current base of knowledge regarding JA is mainly based on microsystem variables that pertain to the biological or temperamental factors influencing JA (Mundy and Neal, 2000; Van-Hecke et al., 2007; Mundy and Jarrold, 2010). For example, these studies emphasize the child's degree of communicational competency or maternal characteristics as predictors of JA (Kasari et al., 1990; Gaffan et al., 2010). It was also found that overall gender does not predict JA in and of itself (Mundy et al., 2007). Research also points to macrosystem level effects, by showing intercultural differences in JA mediated processes. For example, differences were found between Western and Non-Western societies in JA behaviors. Thus it was shown, that in western societies JA seems to be directed more by the child, as opposed to non-western societies in which JA is more parent-directed (Vigil, 2002). This phenomenon was explained by the different belief systems between the Chinese culture and the British culture regarding the child's abilities and needs (Vigil, 2002).

The reference to JA in regard to the mesosystem and exosystem is scarce in current literature, although cultural values are expected to be expressed at these levels as well. It is known that developmental variations exist in ESM's intermediate levels, such as the effect of socio-economic status (SES) in a certain ethnic community. These variations are evident in the academic area (Zill et al., 1995) and the socio-emotional area (Bradley and Corwyn, 2002; Zhang et al., 2009). Similarly, different developmental norms were found among rural and urban communities in measures such as motor development, speech, visuo-spatial processes (Polyakov, 2008), and adaptive living skills (Bornstein et al., 2005). The current study intends to add to this knowledge base concerning intermediate-scale societal variations and highlight the potential relations between different ecological contexts and dyadic JA.

An important component to be considered in this context is that of gender. The relation between cultural characteristics and individual measures might be moderated by the child's gender. All in all, boys and girls seem to show differences in interactional styles from very early on. For example, empirical research has shown that from toddlerhood, girls tend to express more affect than boys (Dunn et al., 1987). It is also evident that boys are encouraged toward self-assertion while girls are encouraged to show social orientation (Lanvers, 2004). At preschool age, children also generally show enhanced gender stereotyping, and preference for specific toys, i.e., household games for girls and construction games for boys (Desouza and Czerniak, 2002). The degree of attunement to gender-roles is an integral part of any given culture, thus, we may postulate that the aforementioned sensitivity to cultural norms and behaviors is also relevant to the realm of traditional sex-roles.

Societies differ in the degree of adherence to traditional gender roles. As such parent–child interaction differences may reflect culture-dependent promotion of gender roles to different extents. This has been shown at the marcosystem level. For example, non-western cultures have been noted to promote traditional sex-roles to a larger extent than western cultures, evident both in adults and in children (Williams and Best, 1990). This variation is explained by the social-cognitive theory (Bussey and Bandura, 1999) that underlines modeling, enactive experience, and direct tuition as underlying mechanisms in gender role-acquirement. As such, it may be also sensitive to finer socio-cultural cues, such as to exosystem level variables.

The current paper is guided by the framework that macro and micro socio-cultural characteristics play an integral role in parental acclimation of infants to their respective culture by affecting central characteristics of parent–child interaction. This shaping process may be expressed as subtle second-to-second changes in specific gaze cues, posture and affect-regulation dynamics during spontaneous social child-caretaker interactions and be evident even as a function of fine socio-cultural differences.

The Israeli society is highly heterogeneous and is characterized by marked differences at the macro-level. Most socio-cultural research of the Israeli society is concentrated, as in other societies, in understanding the effects of macro-level variables (Birnbaum et al., 2010), while the effects of finer socio-cultural processes on parent–child interaction are yet under-studied. This project was focused on studying differences at the exosystem level, while examining the specificity of the relations between sociocultural characteristics and JA. We sought to study the degree of specificity of this relationship by expecting differences in JA, even when macrosystem level variables are held constant. As such, exosystem level differences are noted within the main-stream community, which is characterized by middle-SES, Jewish religion, with a stable conservative family structure. Three different communities characterize this society (Lavee and Katz, 2003): (1) Secular families that identify themselves less with religious values. Children from these families are educated in institutions that encourage western individualism and a sense of self-fulfillment and exploration; (2) Families belonging to religious communities that also endorse liberal values. Children from these families typically attend religious institutions that emphasize traditional values, but typically also cultivate western modes of thought. These communities highly value the role of shared familial learning, which is an integral part of their daily life; (3) Families belonging to religious communities and are affiliated with institutions that mainly promote traditional and conservative values especially concerning gender. Children from these families grow up in families that hold and encourage traditional familial roles.

We would like to propose, that similar to the finding that show that JA is the mechanism mediating between values and behavior at the macrosystem (Rogoff et al., 1993, 2003), these processes occur also at the exosystem and the mesosystem. Namely, the variations in the value-systems in our sample would manifest themselves in dyadic JA processes as well. The aim of the current study was to assess the effects of adherence to cultural values on the manifestation of JA at 5 years of age (kindergarten age), with a special emphasis on the type of stimuli the child was presented with (varying in social load). We assumed that JA initiation would manifest itself as a function of the toy's social load.

Our primary hypotheses were, first, that overall, irrespective of cultural differences, JA would increase in context of interaction with a social toy relative to a non-social task. This hypothesis is in line with accumulated research that shows an unequivocal preference of humans to orient toward faces and other social stimuli relatively to non-social ones (Bard et al., 1992; Valenza et al., 1996).

Secondly, we hypothesized that community characteristics would be correlated with the initiation of JA among participants. Specifically, we assumed, given that traditional societies cherish family and community values, these societies would tend to share attention in response to stereotypical value-carrying stimuli. Thus, we presumed that more bids for JA would be made among children from traditional communities toward the social stimuli presented. Furthermore, we hypothesized that JA initiation would be explained by gender differences, whereby girls would tend to share the social aspect of stimuli more than boys with their social partner. This hypothesis is based on the notion that girls are known to be generally more socially oriented than boys (Romer et al., 2011).

Specific hypotheses concerning the interactional effects were as follows: (1) an interaction between gender and type of stimulus, so that girls would be more inclined to initiate JA to the social aspects of the stimuli presented (Romer et al., 2011); (2) a triple order interaction between gender, adherence to tradition and type of stimulus, so that girls from more adherent communities would be more inclined to initiate JA to the social aspects of the stimuli presented (Williams and Best, 1990).

As for the parental educational factor of the exosystem level, differences within each of the three communities may be also noted in the level of parental formal education. Parental education has been found to predict various socio-emotional outcomes, including social-referencing and specifically JA (Mundy et al., 2007) and are thus hypothesized to moderate the socio-cultural effect. We hypothesized a moderating role in the relationship between community factors and the initiation of JA sharing to social stimuli.

Finally, to explore the degree of specificity of the effects of culture on behavior, we hypothesized that the differences in JA will be corroborated, to some degree, by differences in affect. In line with work showing a tendency for the initiation of JA to be accompanied by positive affect (Bakeman and Adamson, 1984; Mundy and Acra, 2006), we also postulated similar effects with mean time of positive affect as a dependant variable, so that children will tend to show more positive affect when presented with social stimuli, moderated by gender, community, and education factors.

MATERIALS AND METHODS

PARTICIPANTS

This research is part of a large-scale longitudinal study on child development focusing on 5–7 year olds. The current research included 62 children (33 boys, 29 girls) who were assessed at 5 years of age ($M = 5.5$ years $\pm$ 1 month). All families were Jewish, Caucasian, rated as middle SES, with a conservative family structure. All children in the sample attended kindergartens in their respective communities. The cohort consisted of families varying in level of adherence to tradition, defined by religious status (2 levels) and community type (3 levels), and level of parental education (2 levels). The sample was classified based on religiousness and education, as suggested by Friedman (2011). In order to define the degree of familial tradition and education level, the following indices were created: (1) Adherence to tradition index (ATI)—an index score composed of the families' degree of religiousness and the social composition of the familial community, eliciting three levels of tradition—low, medium, and high. The Low-ATI level group was comprised of families who define themselves as secular—not having a religious ties or traditional practices, and living in urban areas with high access to heterogeneous central population-concentrations, characterized by western values. The Intermediate-ATI level group comprised of families who lead a religious lifestyle, but their community of origin also promotes high tolerant, western standards. These families live in a small rural town in Israel (∼2500 residents) revolving around similar ideological and cultural elements, thus creating a homogenous sub-sample (IBS, 2010). The High ATI Level group is comprised of families who lead a religious lifestyle and are connected to religious communities who advocate high adherence to traditional life style and shy away from ideological western values; (2) Parental education index—this score was comprised based on the lower level of education attained by the mother or the father. Scores were classified into two levels—low education by Israeli standards, (i.e., no academic degree) and high education (i.e., at least a bachelor's degree or higher).

PROCEDURE

Children and their parents were invited for testing in the laboratory at 5 years of age. Upon arrival, parents provided informed consent, followed by a warm-up period in the testing room, during which the parents filled out a number of questionnaires assessing demographic information and the child became more comfortable in the testing environment and with the experimenter.

Following this period, the parent and child engaged in a focused attention task designed to assess attention behaviors. The child was seated in front of a table while an experimenter, positioned at a 90° angle from the child, presented one of four toys varying in social load for free exploration: a high social load toy was a doll with a doctor's kit; a Mr. Potato Head© with various accessories, and Lego© blocks with miniature figurines, representing intermediate social load; and a construction game with no social elements, Kinex©, acting as a low social load toy. Meanwhile, the parent was seated farther away from the table and was instructed to allow the child free exploration and action with the toys. This 10 min long procedure was divided into four blocks, each lasting 2 min, intermitted by 30 s long breaks. The task was modified from a procedure by Ruff and Capozzoli (2003), by including a set of distracters presented during the dyadic interaction, rendering it into a more complex one. This modification to the paradigm was carried out in order to provide a more dynamic environment for the child, so as to encourage engagement in JA (Kirlik et al., 1993; Leavens and Bard, 2011). In three of the trials, 4 s long visual, auditory, and audio-visual distracters were presented in the background while the child played with the target toy. The order of the toy and distracter presentation was randomly set and counterbalanced between participants. The entire procedure was videotaped for later coding. In the final part of the session mental age was assessed using Griffiths Mental Development Scales (GMDS-ER; Griffiths, 1993) in order to ensure typical development.

The main dependent measures analyzed were the number of times the child directed or redirected the adult's attention to an aspect of the toy, which were coded as joint attentional bids—(JABS) (Carpenter et al., 1998), and the time intervals in which the child showed affective responses during the trials. Inter-rater reliability was calculated based on 5% of the total sample, in which these participant's tapes were coded separately by a second trained rater. Cohen's Kappa was calculated for the JABS and positive affect measures, showing a 0.84 agreement rate for the JABS measure, and a 0.77 agreement rate for affect, supporting a sufficiently high reliability of the measures.

RESULTS

Mean comparisons of demographical characteristics for children and their parents, showed no significant differences between the three ATI levels on any of the measures of age at test, mental age; on neonatal measures of gestation age and birth weight, and on familial measures of maternal and parental education (**Table 1**).

JOINT ATTENTIONAL BIDS (JABS)

In order to test the effects of the independent factors on children's JABS and expressed affect, measures of JA were analyzed with a 3 × 3 × 2 × 2 mixed design analysis of variance (ANOVA), using toy social load (high, medium, low), degree of community ATI (high, medium, low), gender, and parental education index (high\low) as independent variables. The effects for JABS are presented in **Table 2**.

Results, presented in **Table 2**, show a main effect for type of stimulus. In order to identify the source of this effect, a within-subject *post-hoc* test was carried out. This analysis showed the frequency of JABS was three times higher when the child engaged with social stimuli ($M = 1.86 \pm 0.22$ for the high social load, $M = 1.91 \pm 0.26$ for the medium social load relatively to non-social stimuli ($M = 0.63 \pm 0.12$), thereby supporting the first hypothesis that JABS increase as a function of social content. This analysis, detailed in **Table 2** also yielded support for the effects of the following interactions.

TYPE OF TOY × GENDER

An interaction of Type of toy × Gender was found, $F_{(2, 49)} = 4.06$, $p < 0.05$, $\eta^2 = 0.142$. *Post-hoc* analysis revealed that the interaction is due to significant differences between girls and boys when presented with the highest level of social load so that girls initiated more JA than boys in the high social load toy context (**Figure 1**).

Table 2 | Tests of within- and between-subjects' effects on number of JABS.

Source	*F*	*P*	Partial eta squared	Observed power
TSL	24.94	**<0.001**	0.504	1.00
TSL × Gender	4.06	**0.023**	0.142	0.696
TSL × ATI level	1.19	0.322	0.045	0.360
TSL × Education level	1.11	0.338	0.043	0.234
TSL × Gender × ATI level	3.61	**0.009**	0.126	0.860
TSL × Gender × Education	5.36	**0.008**	0.179	0.818
TSL × ATI level × Education	3.55	**0.010**	0.124	0.853

The bold values show the precise significance level. Computed using alpha = 0.05; TSL, toy social load; ATI, adherence to tradition index.

TYPE OF TOY × COMMUNITY × GENDER

A triple interaction of Type of toy social load × Community × Gender was also found, $F_{(4, 100)} = 3.61$, $p < 0.01$, $\eta^2 = 0.126$ (**Figure 2**). *Post-hoc* simple effects analysis shows that in the highest level of ATI, a significant difference between boys and girls was evident, with the presentation of the highest level of social load. Girls from the High-ATI level made eight times more attempts to create JA than boys when presented with the most social stimulus, thereby supporting the second hypothesis.

TYPE OF TOY × GENDER × EDUCATION

A second triple interaction, Type of toy × Gender × Education, $F_{(2, 49)} = 5.36$, $p < 0.01$, $\eta^2 = 0.179$ was also found (**Figure 3**). The interaction was such that girls in families with higher formal education initiated three times more JABS than boys in families with high education, when presented with the high social load toys. It seems, then, that the education factor augments the interaction effects of Gender × Type of toy, specifically in the high social-load condition.

TYPE OF TOY × COMMUNITY × EDUCATION

The third triple interaction of Type of toy × Community × Education interaction was also supported, $F_{(4, 100)} = 3.55$, $p = 0.01$, $\eta^2 = 0.124$. However, this finding should be treated

Table 1 | Demographic characteristics (mean ± standard errors) of the participants in each group.

	High ATI (*N* = 17)	Mid ATI (*N* = 21)	Low ATI (*N* = 24)	*p*
Gender (% F)	35	52	50	NS
Age at test (m)	66.38 ± 0.92	64.07 ± 0.73	65.81 ± 0.69	NS
Mental age (m)	69.18 ± 1.7	68.48 ± 1.46	70.38 ± 1.25	NS
GA (w)	36.48 ± 0.9	37.22 ± 0.88	37.05 ± 0.78	NS
Birth weight (g)	2566.07 ± 251.46	2656.28 ± 211.18	2671.83 ± 185.49	NS
Mat. educ. level	4.18 ± 0.2	4.09 ± 0.21	4.25 ± 0.16	NS
Pat. educ. level	3.71 ± 0.22	4.19 ± 0.23	4.14 ± 0.17	NS

GA, gestational age; Mat. educ., maternal education; Pat. educ., paternal education.

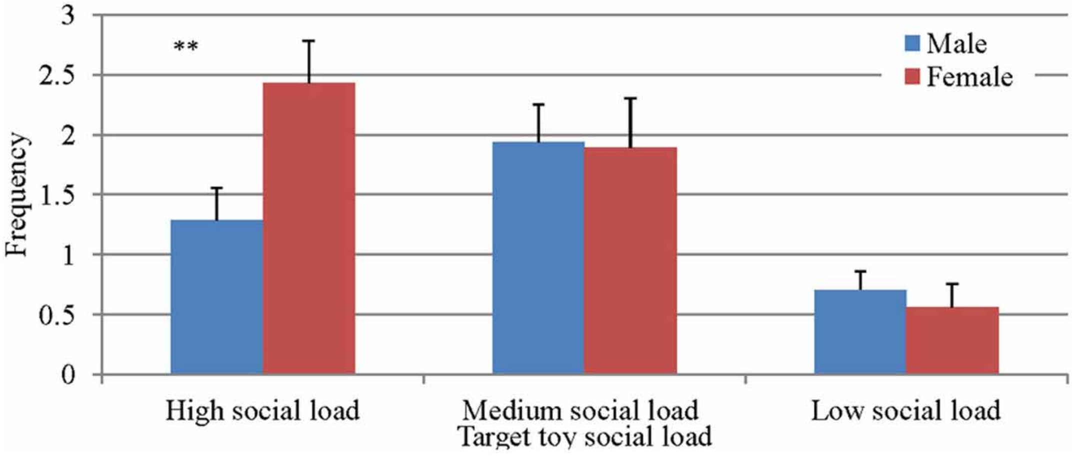

FIGURE 1 | JABS frequencies as a function of gender and social load. **$p < 0.05$.

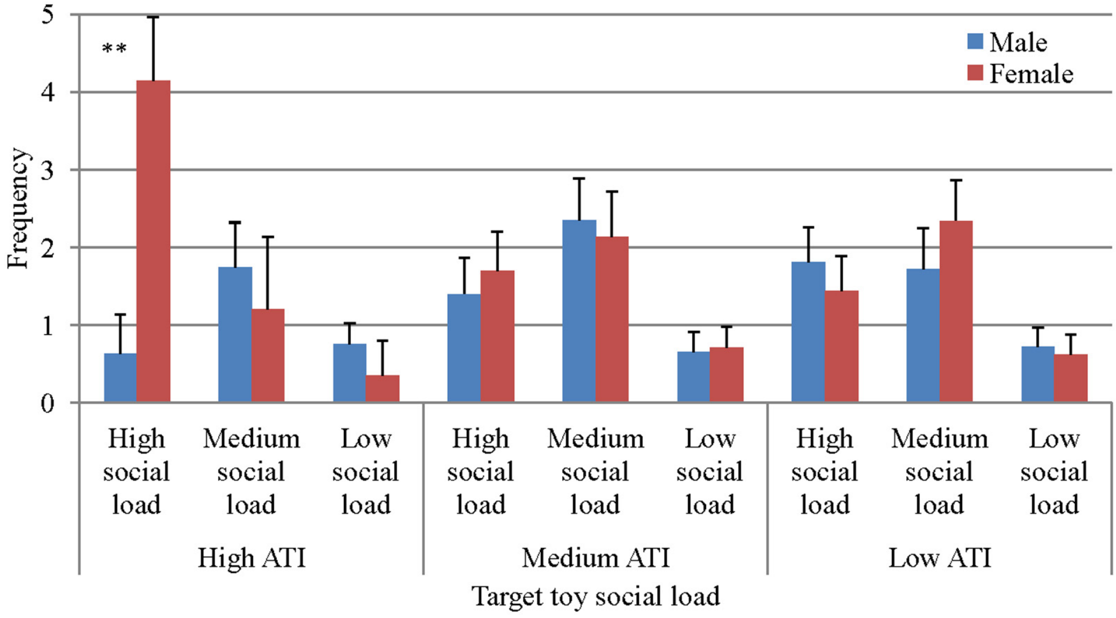

FIGURE 2 | JABS frequency as a function of gender, ATI, and social load (SL). **$p < 0.05$.

with caution and was not followed by post hoc tests in view of unequal cell sizes, particularly due to lack of low education intermediate ATI families.

In order to test if similar effects would be found with affect as a dependant variable, the measure of affect was analyzed using a mixed-design ANOVA with the same independent variables. Results showed that positive affect increased as a function of social load, $F_{(2, 49)} = 22.55$, $p < 0.001$, $\eta^2 = 0.479$ (**Figure 4**).

A within-subjects *post-hoc* test revealed that children spent the longest periods of time expressing positive emotions in the high social load toy condition ($M = 39.67 \pm 5.27$), less so when presented with the intermediate level of social load context ($M = 25.08 \pm 3.76$), and the shortest periods occurred when presented with the lowest level of social load ($M = 12.70 \pm 2.52$). The main effect found with positive affect as a dependent variable supports the hypothesis concerning affect, which assumed children would be inclined to show more positive expression when presented with the social stimuli.

Moreover, a significant Type of toy × Gender interaction effect on positive affect was found, $F_{(2, 49)} = 4.87$, $p < 0.05$, $\eta^2 = 0.166$, also shown in **Figure 4**. This analysis suggests that the aforementioned differences are more pronounced in girls than in boys. No significant effects regarding positive affect were found for ATI or education level.

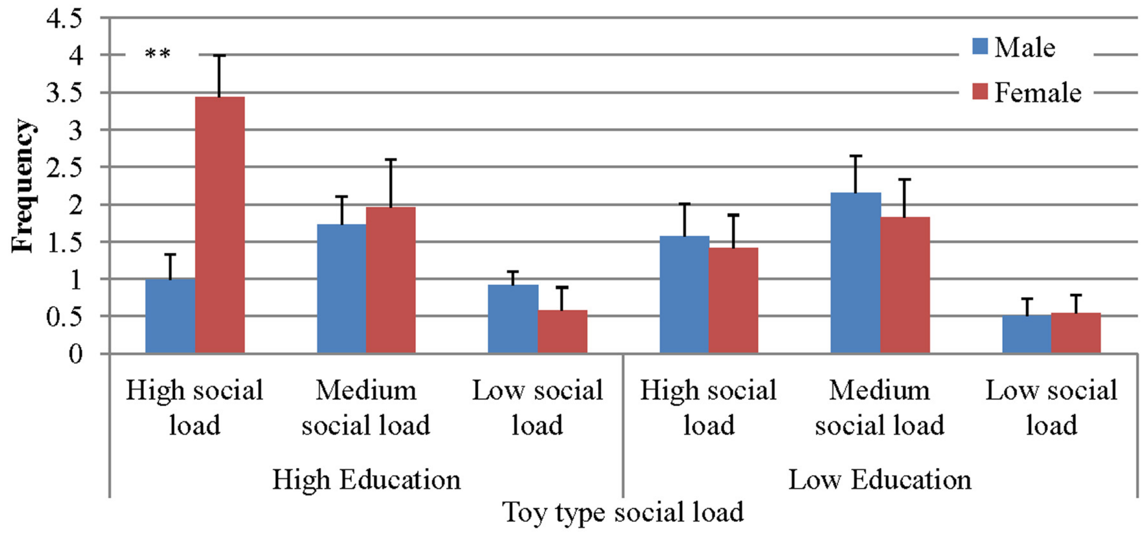

FIGURE 3 | JABS frequencies as a function of gender, education level, and social load. $^{**}p < 0.05$.

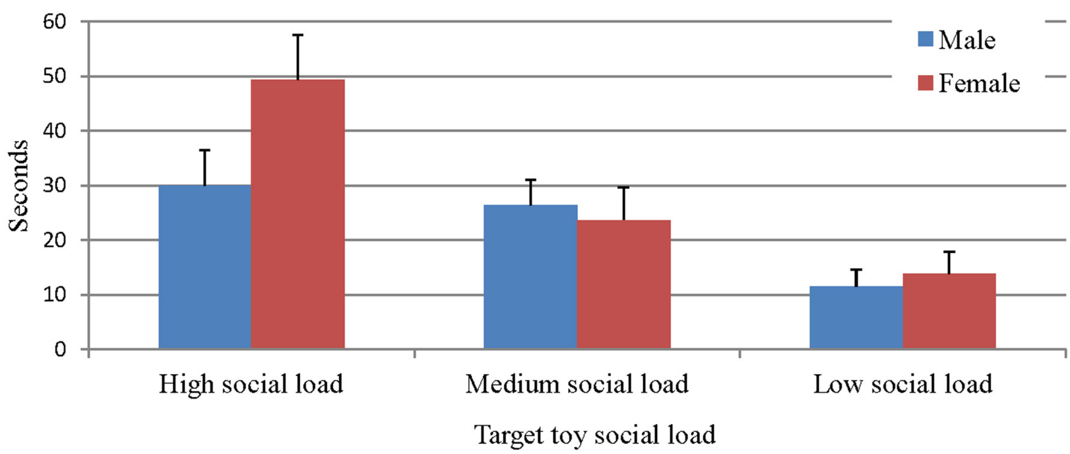

FIGURE 4 | Time of positive affect as a function of gender and social load.

In summary, JABS findings support the main hypothesis concerning JA initiation, showing that overall children indeed tend to initiate more shared attention and express more positive affect when presented with the social stimuli. Support was also found for the hypotheses concerning gender and community interactions with degree of social load, so that the tendency to initiate JA to different stimuli was differential among boys and girls from different ATI levels. Girls, particularly from High ATI communities and high parental education levels, were most affected by the interaction between community and toy load, in which circumstances they initiated most JABS and positive affect. Thus, it may be concluded that ATI level and parental education moderate the relation between gender and social load, explaining a significantly larger portion of the variation.

DISCUSSION

The objective of this study was to broaden the understanding of socio-cultural factors effects on individual behaviors. The social behavior of monitoring a partner's attention to a target was explored at the broad context of societal elements, holding the theoretical stance that the cultural environment in which the individual develops seeps into the micro-processes of social interaction and the child's socio-emotional development. Results seem to be in line with this conceptualization, showing that JA initiation is related to socio-cultural factors in the child's surrounding environment. The interaction effects that were found in the current study point to a notion concerning to "how," by showing that socio-cultural factors map on to affect second-to-second dynamics of children's JA.

The main effect found in our research first validated the notion that JA initiation increases in response to social stimuli. This finding fits well with the social-cognitive framework of JA that views social-learning as a prime goal in the development of JA behavior (Mundy and Acra, 2006). Qualitatively speaking, when playing with the doll, children engaged more in symbolic play and invited the social agents to take part in it. At the non-social contexts, children mainly chose to explore the toy by themselves and initiated less JA, indicating that they preferred less to share the experience with their partners. This finding is compatible with the notion that at the developmental phase of 5 years of age, children express social-interaction intentions by JA, rather than employ it, as at younger ages, to gain concrete information about the target (Tomasello, 1995; Adamson et al., 2004; Mundy and Sigman, 2006; Van-Hecke et al., 2007).

The unique contribution of the current work lays in the moderating roles of socio-cultural factors of this primary interactive behavior. Findings first highlight the notion that socio-ecological factors come into play in the development of JA by interacting with gender and with the level of social load in the task. Overall, gender was not shown to have an effect on JA initiation in and of itself. Yet, girls have shown the preference to initiate JA to social stimuli (i.e., doll) to a greater extent than boys. This finding is supported by literature that shows gender-related differences in toy and game preferences at these ages. It is established that girls tend to prefer playing social games and pretend-play (Desouza and Czerniak, 2002). Several works also show that when engaging in this form of play, girls tend to take on feminine familial roles, including caring and handling (Jones and Glenn, 1991), while boys engage more in construction games (Desouza and Czerniak, 2002). The current study extends this notion to gender differences in JA to high social toys, such as dolls.

Moreover, findings highlight the interaction between gender and socio-cultural features. Findings showed that girls from the highly traditional background were much more affected by the changes in the context in which they created JA, and showed a significant preference to initiating JA to a social stimulus. In this specific community, a "gender stereotypic" discrepancy in shared-attention preferences was augmented. Girls in high ATI as compared with boys in high ATI have shown a higher inclination to initiate JA in the face of highly social stimulus. These differences were not found in the lower ATI levels. Similar effects were shown when comparing between JA initiation preferences of boys and girls from various levels of parental education. This may suggest that girls', and to a lesser extent, boys' preferences to share experiences in the face of social stimuli are reinforced in families with adherent life styles to certain cultural values—traditional and\or academic. This interaction may indicate that JA plays a role in two processes:

1. Traditional societies promote stereotypic gender-roles to a larger extent than non-traditional societies (Williams and Best, 1990). The mechanism for this process is not necessarily one that involves directive teaching, but rather implicit second-to-second gaze exchanges, to provide socio-cultural cues.
2. Girls seem to be more attuned to socio-cultural contexts and to social expectations than boys, as also enabled and manifested by the earlier maturation of the VFPC among girls (Raznahan et al., 2010).

Taken together, the mechanisms involved in the development of children's social interactions, seem to incorporate parental and community characteristics, through the use of JA, which serves as a particularly potent mechanism, scaffolding children's representations of their socio-cultural environment. This mechanism is particularly apparent in girls, in ecologies that are characterized by high adherence to rules, be it through high formal parental education and/or high adherence to traditional conventions. The finding with regard to parental education is intriguing, and may enrich our understanding of the underlying processes involved in intergenerational transmission of cultural values. It has been previously shown that parents vary in their ability to successfully transmit social values (Willson and Sherkat, 1994). Parents with more socioeconomic resources, but not necessarily higher income, were shown to be better able to transmit their cultural values (Myers, 1996). It is probable that parental education has both direct and indirect effects on JABS, by shaping parental attunement to the child's moment-to-moment responses, enabling parents with higher education to implement JA more effectively in order to signal culturally-valued events. The present study may have deepened the understanding regarding the importance of attunement to various cultural value-systems at different levels of the child ecology. It seems that through shared attention to primary aspects of their ecology, children acquire information necessary for them to become adequate members of their society (Leont'ev, 1981; Cole, 1985; Vygotsky, 1987). Children consistently take roles in ongoing interactions and events in their communities, thus appropriating key-elements from their cultures through joint-exploration (Rogoff, 1990). The current study broadens the scope of accumulated knowledge in the field which established that these processes occur at the microsystem level (Mundy and Neal, 2000; Van-Hecke et al., 2007; Mundy and Jarrold, 2010) and the macrosystem level (Vigil, 2002; Vigil et al., 2006). The present findings extend this line to intermediate levels as well, showing that JA might be the mechanism connecting between cultural values and their behavioral manifestations at various ecological levels.

Overall, this research highlights the role of socio-cultural background in the regulation of JA behaviors in social interactions. Importantly, it underscores the potential of a qualitative analysis of JA processes, taking into account the nature of the object to which JA is initiated and the types of contexts and stimuli to which the individual's society of origin directs the sharing of attention and experience. Yet, the modest sample size used in this research ($N = 62$), warrants caution in the interpretation of the results. Moreover, the paradigm was conducted in a structured lab setting, to enable control over multiple environmental factors, a replication in natural settings may highlight further components that need to be explored. Moreover, the study is based on a specifically selected Israeli sample, which was further classified by community ATI as a function of place of residence, religiosity, and the value-system that the family's society revolves around (i.e., goal-orientation or society\family orientation). Pending replication in other samples, future research may continue to explore a wider, ecologically valid model of socio-cultural effects on socio-emotional interactions to better understand the evolving means of culturally mediated sharing of experiences.

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Neighborhood disadvantage and adolescent stress reactivity

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Lower socioeconomic status (SES) is associated with higher levels of life stress, which in turn affect stress physiology. SES is related to basal cortisol and diurnal change, but it is not clear if SES is associated with cortisol reactivity to stress. To address this question, we examined the relationship between two indices of SES, parental education and concentrated neighborhood disadvantage, and the cortisol reactivity of African–American adolescents to a modified version of the Trier Social Stress Test (TSST). We found that concentrated disadvantage was associated with cortisol reactivity and this relationship was moderated by gender, such that higher concentrated disadvantage predicted higher cortisol reactivity and steeper recovery in boys but not in girls. Parental education, alone or as moderated by gender, did not predict reactivity or recovery, while neither education nor concentrated disadvantage predicted estimates of baseline cortisol. This finding is consistent with animal literature showing differential vulnerability, by gender, to the effects of adverse early experience on stress regulation and the differential effects of neighborhood disadvantage in adolescent males and females. This suggests that the mechanisms underlying SES differences in brain development and particularly reactivity to environmental stressors may vary across genders.

Keywords: socioeconomic status, neighborhood disadvantage, parental education, stress reactivity, cortisol, HPA axis

Socioeconomic status (SES), particularly childhood SES, is consistently associated with disparities in disease morbidity and mortality as well as cognitive performance, academic achievement, depression, anxiety, and behavior problems (Adler et al., 1994; Brooks-Gunn and Duncan, 1997; McLoyd, 1998; Bradley and Corwyn, 2002; Chen et al., 2002; Costello et al., 2003; Wadsworth and Achenbach, 2005). Children and adolescents of lower SES report higher levels stress and are routinely exposed to increased family turmoil and more dangerous, crowded and polluted neighborhoods (Brady and Matthews, 2002; Evans, 2004; Goodman et al., 2005). Such chronic stress generates adaptations in the underlying psychological and biological systems that regulate responses to environmental stressors, leading to increased vulnerability to disease and disorder (Adler et al., 1994; Gallo and Matthews, 2003; Shonkoff et al., 2009; Hackman et al., 2010; McEwen and Gianaros, 2010; Miller et al., 2011).

One stress response system, the hypothalamic-pituitary-adrenal (HPA) axis, ultimately produces cortisol in response to physical or psychological threats to well-being. As the function of this system is associated with social factors and is implicated in health and well-being (Gunnar and Quevedo, 2007), it is a plausible mechanism underlying the emergence of disparities. Multiple indices of SES, typically income, education, occupation, or some combination thereof, have been shown to predict differences in baseline measures of cortisol, the diurnal slope of cortisol, total cortisol exposure throughout the day, and the cortisol awakening response in adults (Kristenson et al., 2001; Steptoe et al., 2003; Cohen et al., 2006a,b; Gustafsson et al., 2010, 2011; Hajat et al., 2010; Dowd et al., 2011). In children, family SES has also been shown to predict total overnight cortisol concentration, diurnal slopes, and baseline measures of cortisol in children as well, though the direction of findings has not always been consistent and it is unclear if these relationships extend into adolescence (Lupien et al., 2000, 2001; Evans and English, 2002; Chen and Paterson, 2006; Gustafsson et al., 2006; Evans and Kim, 2007; Chen et al., 2010; Zalewski et al., 2012).

Although response to acute threat is the primary function of the stress system, few studies have investigated the relationship between SES and cortisol reactivity to stress. In adults, education has been both positively (Neupert et al., 2006) and negatively (Fiocco et al., 2007) related to cortisol reactivity, while multiple studies have found no differences in reactivity by SES (Kapuku et al., 2002; Steptoe et al., 2005; Kraft and Luecken, 2009). Even when observed, the causal direction of such effects is difficult to ascertain, as it stands to reason that those who can more successfully manage and respond to performance-based, socially evaluative stressors are more likely to exhibit greater educational achievement in adulthood. In children and adolescents, however, such individual-level social selection is unlikely. In 5-year olds, Blair et al. (2005) found that lower income-to-needs, in a low-SES sample, predicted increased cortisol reactivity. A similar effect was found in children 9.5 years old from a sample with a broader income range (Gump et al., 2009). However, a quasi-experimental intervention designed to relieve extreme poverty through cash payments along with health and educational programs had no effect on cortisol reactivity in children ages 2–6 (Fernald and Gunnar, 2009). In addition, few such studies employ reactivity protocols that enhanced the aspects of social evaluative threat and uncontrollability involved in eliciting a stress response with a standardized protocol (Dickerson and Kemeny, 2004; Gunnar et al., 2009).

To date, studies of cortisol reactivity and SES have also largely omitted investigation of neighborhood components of disadvantage. Neighborhood differences represent a separate and meaningful aspect of SES that is distinct from family based measures of income or education (Krieger et al., 1997; Duncan and Magnuson, 2003; Braveman et al., 2005). Neighborhood disadvantage has been implicated as a predictor of disease morbidity and mortality (Kawachi and Berkman, 2003), lower scores on tasks of verbal ability (Sampson et al., 2008), and reduced serotonergic responsivity to challenge (Manuck et al., 2005). Moreover, experimental data from the Moving to Opportunities (MTO) study have primarily found that moving to more affluent neighborhoods resulted in considerable changes in socioemotional functioning for both adolescents and adults (Sanbonmatsu et al., 2006; Kling et al., 2007). With respect to HPA axis function, lower neighborhood SES predicts lower morning cortisol in adults (Dulin-Keita et al., 2012) and, independently of family SES, lower afternoon cortisol in adolescents (Chen and Paterson, 2006). Only one study has investigated its relationship to reactivity: Kapuku et al. (2002) found no relationship between neighborhood SES and cortisol reactivity in a small sample of 16- to 25-year old males.

Experimental and quasi-experimental research with animals and humans suggests that the relationship between cortisol reactivity and SES, particularly neighborhood disadvantage, may be moderated by gender. Research with animal models indicates that the effect of stressors on HPA axis function and on the development of stress-related brain regions is moderated by gender (McCormick and Mathews, 2007; Weinstock, 2007; Lin et al., 2009). The MTO intervention found that the effects of moving to more affluent neighborhoods varied by gender, with positive effects on mental health and problem behaviors for girls and negative effects for boys (Kling et al., 2007). Moreover, non-experimental changes in neighborhood disadvantage predict changes in boys, internalizing and externalizing problems, with far smaller associations in girls (Leventhal and Brooks-Gunn, 2011). Consequently, the limited or mixed findings concerning SES and cortisol reactivity in the literature may be due to omission of neighborhood SES as well as incomplete consideration of the moderating effects of gender.

The current analysis was designed to address these limitations by examining the relationship between cortisol reactivity and both neighborhood disadvantage and parental education, as moderated by gender, in African–American adolescents. Adolescent participants were exposed to a mild social stressor, a modified version of the Trier Social Stress Test (TSST) (Kirschbaum et al., 1993; Childs et al., 2006; von Dawans et al., 2011). Consequently, this study is uniquely positioned to determine if parental education and neighborhood disadvantage, as moderated by gender, are associated with cortisol reactivity to stress.

MATERIALS AND METHODS

PARTICIPANTS

Participants were 79 African–American adolescents drawn from the control group of a larger longitudinal study of prenatal cocaine exposure ($n = 55$) and a cohort of adolescents, also not exposed to cocaine prenatally, recruited for an earlier study of SES and neurocognitive development ($n = 24$) (Hurt et al., 1995; Farah et al., 2006). Detailed descriptions of participant characteristics were reported previously (Farah et al., 2006; Hurt et al., 2009). One participant did not sleep the night before the stressor protocol and was thus excluded from the analysis, while another was excluded because cortisol values were greater than 3 SD above the mean of the other participants on seven of nine samples. These two samples were combined, and thus analyses included a total of 77 participants (37 female, 48.1%) between the ages of 13 and 18 ($M = 16.4$, SD = 1.2). Consent was obtained from participants aged 18 and older. For participants younger than age 18 both parental or guardian consent and child assent were obtained. The project was approved by the Institutional Review Boards of the University of Pennsylvania and The Children's Hospital of Philadelphia.

INDICATORS OF SOCIOECONOMIC STATUS

We employed a measure of concentrated neighborhood disadvantage based on the 2000 United States (U.S.) census tract for the participant's home address when the stress reactivity protocol was completed (Sampson et al., 1997, 2008). The 77 participants lived in 59 census tracts. Six measures were employed: percentage of individuals below the poverty line, unemployed, and receiving public assistance, as well as the density of African–Americans, children under the age of 18, and female-headed households. Principal components analysis confirmed a single factor of concentrated disadvantage which accounted for 71.4% of the total variance in the six variables. Factor loadings are presented in **Table 1**, which were used to create a continuous, regression-weighted factor score for concentrated disadvantage. Distribution of this factor was within limits for normality.

Parental education was scored as the following for the participant's primary caregiver: raw number of years for those who did not complete high school (score up to 11); 12 for those who completed high school or the General Educational Development (GED) test; 14 for those who completed an Associates degree, some college, or vocational school; 16 for those who completed a Bachelor's degree; 18 for those who competed a Master's degree or some graduate work; 19 for those who completed a Law degree; and 21 for those who completed a Doctoral-level degree (i.e., EdD, MD, PhD, etc.).

STRESSOR PROTOCOL AND PROCEDURE

Participants completed the Trier Social Stress Test for Groups (TSST-G) (von Dawans et al., 2011) a modified version of the

Table 1 | Neighborhood characteristics and concentrated disadvantage factor loading ($n = 77$).

Neighborhood measure*	*M* (SD)	Range (min–max)	Inter-quartile range	Above US average (%)**	Factor loading
Below poverty	23.0 (14.7)	0.0–59.0	12.1–31.7	71.4	0.90
Unemployed	12.5 (6.7)	0.0–27.9	8.0–16.5	85.7	0.92
Public assistance	10.3 (7.2)	0.0–28.2	4.7–14.6	81.8	0.94
African–American	63.8 (36.9)	1.3–97.4	26.0–95.4	87.0	0.60
Under 18	28.3 (5.1)	14.4–43.7	25.0–31.6	71.4	0.71
Female-only household	28.0 (10.4)	4.9–43.4	19.2–36.3	87.0	0.94

*Expressed as the percentage of families in the census tract.

**Percentage of census tracts above US Average.

Table 2 | Parental education, years ($n = 77$).

	Parental education
SUMMARY MEASURES	
Mean (SD)	13.5 (3.0)
Range (min–max)	6–21
Interquartile range	12–15
DISTRIBUTION [NUMBER (%)]	
Less than 12 years	8 (10.4)
12 years	40 (51.9)
Associates degree or some college	10 (13.0)
Bachelor's degree	7 (9.1)
Graduate degree	12 (15.6)

TSST that induces a moderate level of stress (Kirschbaum et al., 1993; Dickerson and Kemeny, 2004). In order to increase social evaluation (Dickerson and Kemeny, 2004) participants underwent the protocol in groups of $2(n = 27, 35.1\%)$ or $3(n = 50, 64.9\%)$ (Childs et al., 2006; von Dawans et al., 2011), matched for gender.

Participants were contacted the evening before their session and instructed to refrain from consuming a major meal 60 min before their session, drinking milk or eating other dairy products 30 min before the appointment, eating acidic or high sugar foods 20 min before the appointment, brushing teeth within 1 h before their session, and consuming alcohol in the 12 h prior to the session (Salimetrics, LLC, State College, PA). All sessions began between 11:30 am and 3:30 pm to control for the diurnal pattern of cortisol, with 84.4% of appointments at 1:00 pm or 1:30 pm.

Figure 1 outlines the protocol for the stress induction procedure. Upon arrival, participants were greeted by the experimenter and directed to sit in a semi-private room where they were able to interact with an experimenter but not with other participants. After completion of the consent process, experimenters conducted a short interview to assess participant compliance with pre-appointment instructions and to survey use of prescribed and non-prescribed medications. To establish a baseline prior to stress induction, participants watched a video with minimally arousing content for 25 min. Participants then performed stressor tasks in a testing room with other group members and an unfamiliar experimenter dressed in a lab coat acting as a judge and directing the testing room activities. To enhance the social evaluative component of the stressor (Dickerson and Kemeny, 2004) participants were told their performance was being videotaped and scored. They were given 6 min to prepare a 3-min speech promoting their candidacy for a summer job, and they each gave their speech facing the video camera, the other participants, and the judge. Subsequently they were instructed to perform serial subtraction by eights, aloud, for 3 min, in front of the same audience. Individuals were given unique four-digit numbers as starting points. If subtraction mistakes were made they were told to re-start from the beginning. Participants were randomly assigned to perform each task first, second, or third. After all participants completed the stressor task they returned to the semi-private room for a 75 min recovery period during which they continued watching the video shown during baseline.

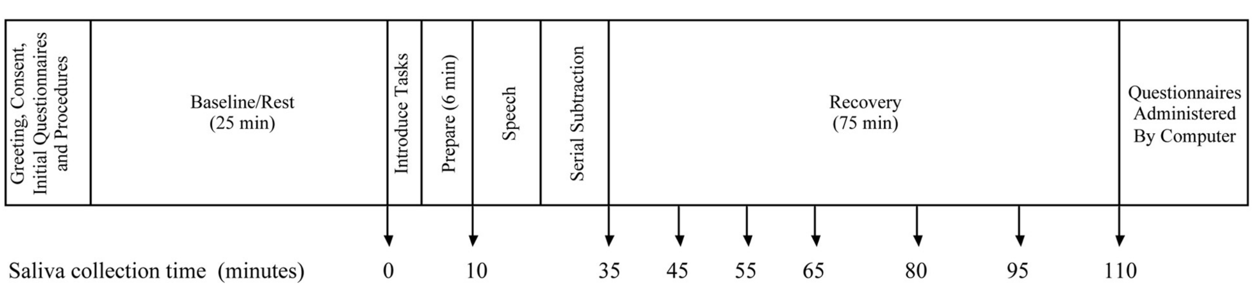

FIGURE 1 | Timeline of procedures.

MEASURES OF THE STRESS RESPONSE

Salivary cortisol was the primary outcome of interest, and saliva samples were collected at nine different times: at baseline, after speech preparation, at the end of the stressor tasks, and 10, 20, 30, 45, 60, and 75 min after the stressor (see **Figure 1**). Saliva samples were collected using the passive drool technique to avoid the potential interference introduced when using oral stimulants to assist in generating saliva (Schwartz et al., 1998; Talge et al., 2005). Samples were frozen immediately at −70°C and transported on dry ice to Salimetrics, LLC (State College, PA) for analysis using enzyme immunoassay techniques. Assays were conducted in duplicate and average cortisol concentrations were used. The test uses 25 μl of saliva per determination has a lower limit of sensitivity of 0.003 μg/dl and standard curve range from 0.012 to 3.0 μg/dl. Intra- and inter-assay coefficients of variation were 3.5 and 5.1% respectively. Due to skewed distributions, the natural log of the average cortisol concentration was the primary dependent measure.

Subjective responses to the protocol were collected during the procedure as well as retrospectively. Participants rated their anxiety level concurrent with the collection of saliva samples using a seven-point Likert-type scale (1 = very calm and relaxed; 3 = feeling pretty calm and relaxed; 5 = a little bit nervous, but not too bad; 7 = very nervous or stressed). After completion of the stressor, at the start of the recovery period, participants were asked how stressful and challenging they found the speech and math tasks, with response choices structured along a seven-point Likert type scale (1 = not at all challenging or stressful, 7 = extremely challenging or stressful).

COVARIATES

Multiple potential confounds were measured and included in analyses in order to rule out effects due to methodological factors and additional participant behaviors that may affect stress responses. Participants' use of prescription and over-the-counter medications, as well as oral contraceptives, was assessed (Kirschbaum et al., 1999; Hibel et al., 2006). Of all classes of medications, only oral contraceptives ($n = 6$), non-steroidal asthma medication ($n = 5$), ibuprofen ($n = 5$), and acetaminophen ($n = 8$) were used by more than three participants and thus included in analyses. Five participants currently smoked cigarettes (6.5%) (Rohleder and Kirschbaum, 2006). Mean hours of sleep the night before was 7.8 (SD = 2.1) while the average time participants had been awake at the beginning of the protocol was 5.7 h (SD = 2.0) (Leproult et al., 1997; Spiegel et al., 1999).

DATA ANALYSIS

Piecewise hierarchical linear modeling (HLM) was the primary analysis strategy [1]. Piecewise HLM is a strategy based on longitudinal growth modeling that allows distinct modeling of the different phases of change over time, permits the separate modeling of reactivity and recovery phases following administration of a stressor, and offers advantages over the use of ANOVA or change scores (Llabre et al., 2001; Hruschka et al., 2005; Bernard and Dozier, 2010). A Level-1 model was estimated that represents the individual change in the natural log of salivary cortisol across the protocol and included both fixed components and random components (intercept and slopes) that were permitted to vary across individuals. Time was recoded into two separate components, to create a two-piece linear model. The first component represents time linearly from baseline through the measures of cortisol taken 10 min after the completion of the stressor (minute 45), capturing the episode of reactivity to the stressor. Saliva collection times (see **Figure 1**) for the reactivity episode were thus coded, in minutes, as 0, 10, 35, 45, 45, 45, 45, 45, and 45. The second linear component represents the episode of recovery from the stressor, the time from 10 min after the completion of the stressor through the end of the protocol. Saliva collection times for the recovery episode were thus coded as 0, 0, 0, 0, 10, 20, 35, 50, and 65. This results in the following Level-1 model:

$$\ln(\text{cort})_{ti} = \pi_{0i} + \pi_{1i}(\text{Reactivity episode})_{ti} + \pi_{2i}(\text{Recovery episode})_{ti} + \varepsilon_{ti} \quad (1)$$

In this model, the natural log of salivary cortisol is predicted by π_{0i}, the intercept, π_{1i}, the linear rate of change during reactivity and π_{2i}, the linear rate of change during recovery. Given the coding of time employed for reactivity and recovery, the intercept, π_{0i}, is an estimate of the natural log of cortisol concentration at baseline before administration of the stressor. Level-2 equations were also estimated in which the variance in the intercept and slope parameters at Level-1 were predicted by parental education and neighborhood disadvantage, as continuous variables, and their interaction with gender. Analyses were conducted in HLM6 (Raudenbush et al., 2004) using full maximum likelihood estimation. All variables included in analyses were grand-mean centered. Descriptive data were analyzed using SPSS 20.0 (IBM: New York, NY).

First an unconditional linear piecewise growth model was created, and then separate models were created for neighborhood disadvantage and parental education as independent variables at Level-2. Each model included gender and the interaction of either education or disadvantage with gender. For example, for neighborhood disadvantage, the basic Level-2 equations were as follows:

$$\pi_{0i} = \beta_{00} + \beta_{01}(\text{Disadvantage})_i + \beta_{02}(\text{Gender})_i + \beta_{03}(\text{Disadvantage} \times \text{Gender})_i + \zeta_{0i} \quad (2)$$

$$\pi_{1i} = \beta_{10} + \beta_{11}(\text{Disadvantage})_i + \beta_{12}(\text{Gender})_i + \beta_{13}(\text{Disadvantage} \times \text{Gender})_i + \zeta_{1i} \quad (3)$$

$$\pi_{2i} = \beta_{20} + \beta_{21}(\text{Disadvantage})_i + \beta_{22}(\text{Gender})_i + \beta_{23}(\text{Disadvantage} \times \text{Gender})_i + \zeta_{2i} \quad (4)$$

We then included potential control variables individually and noted each variable which was significant at a level of $p < 0.10$ and for which the fit of the prediction model was improved (Singer and Willett, 2003). These variables were gender, age, group size, current cigarette smoking, hours of sleep the night

[1] Subsample analyses found that a piecewise model was a better fit for the data than a quadratic model of change (data not shown).

before, hours since awakening, and the use of oral contraceptives, non-steroidal asthma medication, ibuprofen, and acetaminophen. Next, we created a basic prediction model including all variables identified in the previous step and then removed non-significant ($p > 0.05$) control variables sequentially starting with the highest p-value, until only significant control variables remained. Significant interaction effects were then examined by re-centering gender in two models, with males and females coded as 0 and 1 in one model, and 1 and 0 in the second model. Consequently, the slope coefficient of concentrated disadvantage in each model is that for the gender coded as 0; by re-centering in this manner, estimates of the effect of concentrated disadvantage for each gender are obtained. Finally, we examined if findings from this complete prediction model were explained by differences in subjective appraisals of and responses to the stressor.

RESULTS

SAMPLE CHARACTERISTICS: SOCIOECONOMIC STATUS

Characteristics of the 59 unique census tracts participants lived in are delineated in **Table 1**. Across these 59 tracts, on average, 23.0% (SD = 14.7) of individuals were below the poverty line, with percentages below the poverty line ranging from 0 to 59.0%. Neighborhood unemployment averaged 12.5% (SD = 6.7), while 10.3% (SD = 7.2) of neighborhood residents were receiving public assistance. These levels are above the United States average, and range from neighborhoods with the near absence of disadvantage to neighborhoods with highly concentrated disadvantage. Descriptive statistics for parental education are presented in **Table 2**. Average parental education for families was 13.5 (SD = 3.0), and ranged from 6 to 21 years. Eight participants (10.4%) had a primary caregiver with less than a high school education while 40 participants (51.9%) had a primary caregiver with a high school education. Parental education and concentrated disadvantage were correlated ($r = -0.55$, $p < 0.001$), such that lower parental education was related to higher levels of neighborhood disadvantage.

SUBJECTIVE APPRAISAL OF THE STRESSOR

Peak anxiety ratings during the stressor were in the moderate range ($M = 4.5$, SD = 1.5), while the average change in rating from baseline to peak was 2.4 (SD = 1.7) on the seven-point Likert scale. After stressor administration, both the math ($M = 4.4$, SD = 1.8) and speech ($M = 4.5$, SD = 1.7) tasks were rated as moderately challenging on a seven-point scale, while the overall protocol was rated as moderately stressful ($M = 4.0$, SD = 1.9).

PREDICTING BASELINE CORTISOL, REACTIVITY, AND RECOVERY: INTERACTION BETWEEN GENDER AND CONCENTRATED DISADVANTAGE

Seventy-four participants (96.1%) had complete data for salivary cortisol at Level 1, while three participants each were missing one data point, for a total of 690 Level 1 observations. The unconditional piecewise growth model for cortisol level over time across the protocol yielded a non-significant, positive fixed effect for the reactivity episode ($B = 0.007$, $p = 0.64$) and a significant fixed effect for the recovery episode, in the negative direction ($B = -0.007$, $p < 0.001$). However, the random effects for the intercept ($\sigma_0^2 = 0.22$, $p < 0.001$) estimating baseline cortisol before the stressor, the slope of the reactivity episode ($\sigma_1^2 = 0.0015$, $p < 0.001$), and the slope of the recovery episode ($\sigma_2^2 = 0.0004$, $p < 0.001$) were all significant. This indicates that, on average, the stress manipulation did not generate an increase in cortisol above baseline. However, there are significant individual differences in intercept as well as the slope during reactivity and recovery, such that some participants exhibited increases in cortisol while others did not, and consequently there is sufficient variance to predict systematically with indicators of SES and gender.

As illustrated in **Table 3**, Model A, the main effect of concentrated disadvantage on reactivity was borderline significant ($B = 0.003$, $p = 0.052$, $r_{\text{effect}} = 0.23$). However, the interaction between gender and concentrated disadvantage was significant for both reactivity ($B = -0.006$, $p = 0.03$, $r_{\text{effect}} = 0.25$) and recovery ($B = 0.004$, $p = 0.009$, $r_{\text{effect}} = 0.30$). Neither concentrated disadvantage ($B = -0.07$, $p = 0.19$, $r_{\text{effect}} = 0.15$) nor its interaction with gender ($B = -0.03$, $p = 0.81$, $r_{\text{effect}} = 0.03$) predicted the intercept, or baseline prior to the stressor. This effect was specific to the neighborhood measure of SES; as described in **Table 3**, Model B, there were no significant effects on the intercept, reactivity, or recovery of parental education (all $p \geq 0.12$) or its interaction with gender (all $p \geq 0.10$)[2].

To further specify the nature of the interaction between concentrated disadvantage and gender, Model A was run twice with gender re-centered, one model with males and females coded as 0 and 1, respectively, and one with males and females were coded as 1 and 0. Consequently, the slope coefficient of concentrated disadvantage in each model is for that gender coded as 0. With male coded as 0, and coefficients for disadvantage thus reflecting the effect for males, higher concentrated disadvantage predicted increased cortisol reactivity ($B = 0.006$, $p = 0.004$, $r_{\text{effect}} = 0.33$) and a steeper decline during recovery ($B = -0.003$, $p = 0.003$, $r_{\text{effect}} = 0.34$). No effects were observed for the intercept ($B = -0.06$, $p = 0.43$, $r_{\text{effect}} = 0.09$). With females coded as 0, and coefficients for disadvantage thus reflecting the effect for females, the effect of concentrated disadvantage was not significant for the intercept ($B = -0.09$, $p = 0.29$, $r_{\text{effect}} = 0.13$), reactivity ($B = 0.0004$, $p = 0.85$, $r_{\text{effect}} = 0.02$) or recovery ($B = 0.001$, $p = 0.40$, $r_{\text{effect}} = 0.10$).

Following Aiken and West (1991), we selected values of concentrated disadvantage that are 1.5 SD's above and below the grand mean to illustrate the interaction effect in **Figure 2**. Notably, the intraclass correlation coefficient (ICC) for cortisol in males was 0.65, while the ICC for females was 0.52. This is indicative of considerable between-subject variability in both genders, suggesting the interaction is not explained by the absence of variability between subjects in females, but nevertheless more variability in cortisol is explained by between subjects factors in males than in females. In addition, it is unlikely that these results are explained by maturational differences, as age is neither

[2]Subsample analyses found similar effects employing alternative analysis approaches, including a mixed model ANOVA and area under the curve as compared to baseline, a summary measure of reactivity (data not shown).

Table 3 | Linear piecewise model of salivary cortisol.

Parameter	Model A: Concentrated Disadvantage		Model B: Parental Education	
	B	r_{effect}	***B***	r_{effect}
FIXED EFFECTS				
Initial status, π_{0i}				
Intercept	−2.00***	0.98	−1.99***	0.97
Concentrated disadvantage	−0.07	0.15		
Parental education			0.02	0.13
Gender	0.27*	0.28	0.29**	0.30
Disadvantage × Gender	−0.03	0.03		
Education × Gender			0.03	0.09
Sleep	−0.05*	0.26	−0.05*	0.25
Episode 1, reactivity, π_{1i}				
Intercept	0.001	0.07	0.001	0.10
Concentrated disadvantage	0.003^	0.23		
Parental education			0.000	0.08
Gender	−0.006*	0.27	−0.0007*	0.26
Disadvantage × Gender	−0.006*	0.25		
Education × Gender			0.002	0.18
Asthma med (non-steroidal)	0.011*	0.28	0.01**	0.31
Episode 2, recovery, π_{2i}				
Intercept	−0.007***	0.74	−0.007***	0.73
Concentrated disadvantage	−0.001	0.18		
Parental education			0.000	0.18
Gender	−0.001	0.09	−0.001	0.06
Disadvantage × Gender	0.004**	0.30		
Education × Gender			−0.001^	0.19
	Estimate	**SE**	**Estimate**	**SE**
RANDOM EFFECTS				
Level 1				
Within-person, σ_ε^2	0.042	0.0027	0.042	0.0027
Level 2				
Initial status, σ_0^2	0.194	0.035	0.194	0.036
Episode 1, reactivity, σ_1^2	0.0001	0.00002	0.0001	0.0000
Episode 2, recovery, σ_2^2	0.00003	0.00001	0.0000	0.0000
Covariance, σ_0^1	−0.0017	0.0007	0.0019	0.0007
Covariance, σ_0^2	−0.0007	0.0004	−0.0006	0.0004
Covariance, σ_1^2	−0.00002	0.00001	0.0000	0.0000
R_ε^2	0.67		0.67	
R_0^2	0.15		0.14	
R_1^2	0.20		0.13	
R_2^2	0.25		0.00	

$^\wedge p < 0.10$; $^* p < 0.05$; $^{**} p \leq 0.01$; $^{***} p < 0.001$.

correlated with disadvantage ($r = 0.11$, $p = 0.37$) nor gender ($t = -0.46, p = 0.64$).

INDEPENDENCE FROM SUBJECTIVE RESPONSE

Do the differences observed in cortisol response, with high reactivity among low SES boys, reflect differences in physiological response to subjectively appraised stressors of a given intensity, or differences in the subjective appraisals themselves? A series of models was run to determine if any such factors explained the observed interaction in Model A. Self-rated anxiety at Level 1, measured concurrently with salivary cortisol and added to Model A, did not predict salivary cortisol ($B = -0.008$, $p = 0.33$, $r_{effect} = 0.04$). Next, a set of models were run in which measures of subjective appraisal and response to the stressor as well their interaction with gender were added to Model A at Level 2. In these models neither anxiety reactivity (peak minus baseline) ($B = -0.00006$, $p = 0.94$, $r_{effect} = 0.01$), the appraisal of the stressor ($B = -0.0002$, $p =$

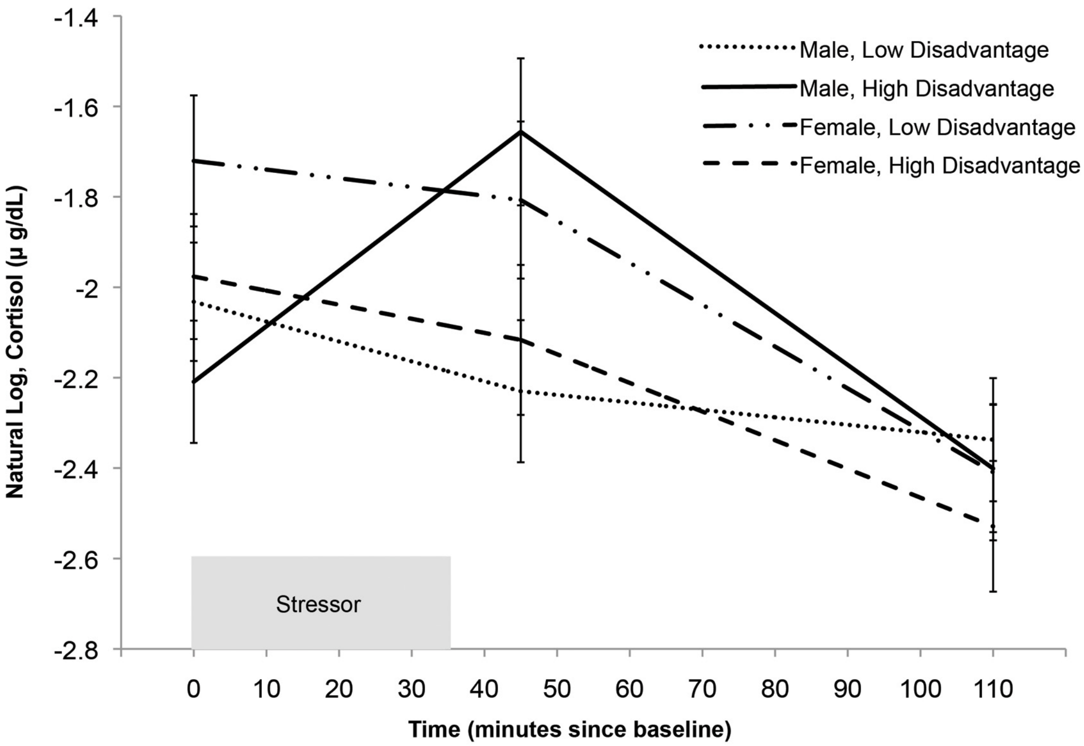

FIGURE 2 | Predicted cortisol reactivity by gender and level of concentrated disadvantage. Model-based graphs of cortisol concentration during the reactivity and recovery periods protocol by gender and level of concentrated disadvantage. This model controls for the effects of sleep and asthma medication (non-steroidal). For illustrative purposes we selected two values representing high and low disadvantage, 1.5 SD above and below the mean (following Aiken and West, 1991). Error bars represent standard error.

0.78, $r_{\text{effect}} = 0.03$), math difficulty ratings ($B = -0.0004$, $p = 0.61$, $r_{\text{effect}} = 0.06$), or speech difficulty ratings ($B = 0.001$, $p = 0.07$, $r_{\text{effect}} = 0.22$) predicted reactivity. In addition, none of the interactions between these indices of subjective appraisal and gender were significant predictors of reactivity (all $p > 0.27$). With respect to recovery, neither anxiety reactivity ($B = 0.0001$, $p = 0.80$, $r_{\text{effect}} = 0.03$), the appraisal of the stressor ($B = -0.00005$, $p = 0.91$, $r_{\text{effect}} = 0.01$), math difficulty ratings ($B = 0.0003$, $p = 0.50$, $r_{\text{effect}} = 0.08$), or speech difficulty ratings ($B = -0.00004$, $p = 0.94$, $r_{\text{effect}} = 0.01$) were significant predictors. As with reactivity, none of the interactions between these indices of subjective appraisal and gender were significant predictors of recovery reactivity (all $p > 0.19$). In all models the interaction between gender and disadvantage remained a significant predictor of reactivity (all $p \leq 0.047$) and recovery (all $p \leq 0.009$).

DISCUSSION

In this analysis we found that concentrated neighborhood disadvantage, but not parental education, was associated with cortisol reactivity and recovery. However, this relationship was moderated by gender, such that higher concentrated disadvantage was associated with higher cortisol reactivity and steeper recovery in boys alone. This association was not explained by differences in subjective reactivity to the stressor. This highlights the particular importance of neighborhood effects and that SES differences in brain development and particularly reactivity to environmental stressors may vary across genders.

The direction of this association is consistent with prior studies in children and adolescents indicating that lower SES, particularly low income, predicts greater stress reactivity (Blair et al., 2005; Gump et al., 2009). In addition, it may help to reconcile prior reports with the null findings on stress reactivity of a quasi-experimental intervention composed of cash payments as well as health and educational programs (Fernald and Gunnar, 2009). In particular, analyses of income effects that do not measure and include neighborhood disadvantage may find income effects that are a proxy for neighborhood effects, given their correlation; if this were the case, an intervention targeting income would be expected to produce null results. However, it remains possible that this intervention did not predict reactivity because it was a more rigorous design that better accounted for additional unobserved variables, and a direct test of the relative associations of income and neighborhood disadvantage remains to completed. Somewhat surprising was the absence of a relationship between SES indicators and baseline cortisol prior to the stressor, though this is likely explained by the fact that most SES effects are found on broader measures of diurnal function and that null results have been found previously in adolescents (Lupien et al., 2000, 2001; Evans and English, 2002; Chen and Paterson, 2006; Gustafsson et al., 2006; Evans and Kim, 2007; Zalewski et al., 2012).

The positive relationship between neighborhood disadvantage and stress reactivity is consistent with the Biological Sensitivity to Context and Adaptive Calibration models of stress reactivity (Del Giudice et al., 2011; Ellis and Boyce, 2008), which predict higher levels of responsivity in more stressful, dangerous environments, as well as possible gender differences which emerge across development. These models may also help integrate these findings within the broader adversity literature, particularly that concerning abuse, which has often been found to be predict decreased cortisol reactivity (Carpenter et al., 2007, 2009; Elzinga et al., 2008), though this is not always the case (Heim et al., 2000). In particular, the adaptive calibration model distinguishes between the stressful, unpredictable conditions associated with lower SES and neighborhood disadvantage, which are predicted to promote increased reactivity to stress, consistent with the current findings and in contrast with more severe or traumatic stress that promotes an unresponsive pattern (Del Giudice et al., 2011).

In addition, increased reactivity in boys from neighborhoods with high levels of disadvantage may increase their vulnerability to environmental effects (Ellis and Boyce, 2008; Belsky and Pluess, 2009), thereby increasing the likelihood of future problems given the stressful and unpredictable neighborhoods they are exposed to. Moreover, in a meta-analysis, Chida and Hamer (2008) found that reduced HPA-axis reactivity was a predictor of positive psychological traits and states. However, studies have found that increased reactivity is predictive of better executive function and mood (Blair et al., 2005; Burke et al., 2005). Much remains to be understood about the role of stress reactivity in important life outcomes, but it seems likely that the functional importance of such increased reactivity may depend on the outcome domain and the future environments adolescents are exposed to.

The specificity of the association between neighborhood disadvantage and reactivity suggests that the family resources associated with education do not underlie differences in reactivity. It remains to be determined what mechanism is driving these effects in boys. It has been suggested that boys are more vulnerable to neighborhood disadvantage due to differences in the amount of unsupervised free time allowed by parents (Hilbrecht et al., 2008; Leventhal and Brooks-Gunn, 2011). Peer effects are another candidate mediator, as social status among peers, moderated by gender, is a better predictor of morning cortisol than family SES (West et al., 2010). In addition, any potentially causal effects of neighborhood disadvantage may be mediated by parenting practices (Repetti et al., 2002; Luecken and Lemery, 2004; Hackman et al., 2010) or the manner in which stressors are cognitively framed (Chen et al., 2012). Through any such mechanism, it is likely that effects are transmitted at least in part through changes in gene expression for the glucocorticoid receptor leading to heightened responses to stress (Miller et al., 2009).

One potential limitation to interpretation of the interaction between gender and neighborhood disadvantage is the association of gender and reactivity, in which adolescent females exhibited smaller responses to the stressor overall. This is consistent with prior findings that females exhibit smaller responses to such performance based stress protocols, rather than social rejection-based protocols (Kirschbaum et al., 1999; Stroud et al., 2002; Dedovic et al., 2009). As such, it could be argued that the interaction is primarily due to the lack of response among females and that only a main effect of disadvantage would be observed with a different stressor protocol. However, despite the overall main effect of gender, the intraclass correlation within females indicates that nearly half of the variability of cortisol across time is between subjects, suggesting considerable variability exists to predict systematic differences. Concentrated disadvantage, however, does not significantly predict such differences in females. Moreover, moderation of neighborhood effects by gender is consistent with quasi-experimental and observational studies of neighborhood effects on children and adolescents (Kling et al., 2007; Leventhal and Brooks-Gunn, 2011) as well as experimental literature in animals indicating that the impact of environmental stressors on the HPA axis is moderated by gender (McCormick and Mathews, 2007; Weinstock, 2007; Lin et al., 2009). Nevertheless, the stability of this interaction across stressor types bears empirical investigation.

As with all observational studies on SES, it is impossible to firmly establish the direction of causality, as similar heritable factors may influence both socioeconomic position and stress reactivity. However, multiple lines of evidence suggest this effect is likely to be due to social causation, at least in part. First, animal literature experimentally demonstrates the effect of environment on stress reactivity (Zhang et al., 2006). In addition, twin studies suggest that environmental factors are the primary determinants of the stress response during the first exposure to a stressor, especially for those raised under conditions of adversity (Federenko et al., 2004; Ouellet-Morin et al., 2008; Steptoe et al., 2009).

Despite the specificity of the relationships demonstrated here between neighborhood disadvantage and cortisol reactivity and recovery, we recognize that such claims warrant caution. In particular, although we employed a measure of neighborhood concentrated disadvantage based on the child's census tract of residence, the number of participants in each tract was too small to treat individuals as nested within the neighborhood as a higher level of organization (Subramanian et al., 2003). Consequently, this analysis is not able to model the inherently multilevel nature of neighborhood effects.

In summary, SES as indexed by concentrated neighborhood disadvantage is associated with cortisol reactivity and recovery in boys, but not in girls. These findings suggest that the mechanisms underlying SES differences in the neural systems underlying stress regulation vary across genders.

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Frontal EEG/ERP correlates of attentional processes, cortisol and motivational states in adolescents from lower and higher socioeconomic status

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Event-related potentials (ERPs) and other electroencephalographic (EEG) evidence show that frontal brain areas of higher and lower socioeconomic status (SES) children are recruited differently during selective attention tasks. We assessed whether multiple variables related to self-regulation (perceived mental effort) emotional states (e.g., anxiety, stress, etc.) and motivational states (e.g., boredom, engagement, etc.) may co-occur or interact with frontal attentional processing probed in two matched-samples of fourteen lower-SES and higher-SES adolescents. ERP and EEG activation were measured during a task probing selective attention to sequences of tones. Pre- and post-task salivary cortisol and self-reported emotional states were also measured. At similar behavioural performance level, the higher-SES group showed a greater ERP differentiation between attended (relevant) and unattended (irrelevant) tones than the lower-SES group. EEG power analysis revealed a cross-over interaction, specifically, lower-SES adolescents showed significantly higher theta power when ignoring rather than attending to tones, whereas, higher-SES adolescents showed the opposite pattern. Significant theta asymmetry differences were also found at midfrontal electrodes indicating left hypo-activity in lower-SES adolescents. The attended vs. unattended difference in right midfrontal theta increased with individual SES rank, and (independently from SES) with lower cortisol task reactivity and higher boredom. Results suggest lower-SES children used additional compensatory resources to monitor/control response inhibition to distracters, perceiving also more mental effort, as compared to higher-SES counterparts. Nevertheless, stress, boredom and other task-related perceived states were unrelated to SES. Ruling out presumed confounds, this study confirms the midfrontal mechanisms responsible for the SES effects on selective attention reported previously and here reflect genuine cognitive differences.

Keywords: socioeconomic status, event-related potentials (ERPs), EEG power, EEG asymmetry, auditory selective attention, salivary cortisol, executive control and self-regulation

INTRODUCTION

Developmental studies focusing on behavioural or imaging methods such as event-related potentials (ERPs) and other electroencephalographic (EEG) techniques have shown that frontal brain areas of children with higher and lower family socioeconomic status (SES) seem to be recruited differently during laboratory tasks probing executive attention and cognitive control (see reviews in Hackman and Farah, 2009; Lipina and Colombo, 2009; Raizada and Kishiyama, 2010). In particular, an increasing body of work is focusing on the relationship between SES and the neural responses underlying children's selective attention, especially ERP signatures occurring very early after stimulus presentation (e.g., 100–200 ms). The findings in a small number of studies on auditory selective attention focusing on some of those specific waveforms (D'Angiulli et al., 2008a; Stevens et al., 2009) suggest that, while higher SES children of various ages "filter out" distracters, lower SES children attend to distracters (the irrelevant information) as much as they attend to targets (the relevant information), without apparent differences in terms of behavioural performance. Furthermore, studies based on visual novelty paradigms have shown evidence of *frontal hypo-activity* in lower-SES children as reflected by reduced early activation, compared to that recorded in higher-SES comparison children (Kishiyama et al., 2009).

Generally, the mentioned findings have been interpreted in terms of cognitive differences even though the spatial resolution of the measures used cannot rule out the possible contributions of emotional or motivational processes controlled by overlapping or adjacent frontal functional networks. Specifically, the anterior attention system (Posner and Rothbart, 2007, see also Lipina and Posner, 2012) is thought to control or direct attention and action by modulating cognitive and affective processing through two major functional subdivisions of the anterior cingulate cortex (ACC). The differing environments of lower- and higher-SES children may reflect an instance in which the anterior attention system may develop divergent ways of integrating cognitive and emotional aspects involved in adaptation and self-regulation (Davis et al., 2002; Blair, 2010). Differential childhood experiences may influence aspects of brain development associated with emotion regulation and social behavior, influencing the maturation of key brain areas, such as the prefrontal cortex (PFC), as well as their neural networks and interactions (Farah et al., 2006; Hackman and Farah, 2009). Thus, the hypothalamic-pituitary-adrenocortical (HPA) axis controlling cortisol regulation plays an important role at the intersection of these brain areas and the physiological and behavioural regulatory processes (Hackman et al., 2010). Plausibly, midline frontal areas involved in executive functions and top-down control of the autonomic nervous system through the HPA axis may be vulnerable to aversive experiences associated with SES (Shonkoff et al., 2009). For instance, increasing evidence indicates that lower-SES children show heightened activation of stress-responsive systems as reflected by elevated cortisol (Lupien et al., 2000, 2001). Particularly relevant for the present study, Tomarken et al. (2004) found evidence of left frontal hypo-activity in lower-SES 12–14-year-old adolescents by examining resting EEG power alpha frequency asymmetry; this is consistent with the adult and developmental findings of correlations between aversive emotional reactions, increased cortisol, and left EEG hypo-activity—to be specific, greater right, relative to left, frontal activation (Coan and Allen, 2004; see Kim and Bell, 2006, for a review specific to childhood).

The few developmental studies directly assessing aspects of neural activity related to the anterior attention system in lower SES children have emphasized the importance of theta oscillations. In a longitudinal study of resting EEGs, Otero and colleagues, (Otero, 1994, 1997; Otero et al., 2003) followed two cohorts of 22 lower- and higher-SES children from the age of 18–30 months to 5–6 years. Although differences in EEG power between the two groups declined with age, there were persistent differences in frontal theta and occipital/left temporal alpha bands. Similar differential prevalence in theta EEG tonic activity was found in another study in older under-privileged children (Harmony et al., 1988), suggesting evidence of significantly more theta than alpha power in lower-SES children. Previously, we reported evidence also suggesting that differences between SES groups in task-dependent frontal and midline theta activation could reflect differences in effortful regulation during selective attention deployment (D'Angiulli et al., 2008b). It is known that event-related increases in theta power are correlated with unspecific factors such as attentional demands, task difficulty, and cognitive load (Schacter, 1977; Gevins et al., 1997, 1998; see reviews by Sauseng et al., 2006, 2010). Unlike the resting activity, task-dependent theta power is typically inversely related to activity in the lower spectrum of the alpha band power (Klimesch, 1999), therefore, if defining patterns of activity such as hypo-activity/asymmetry were observed for theta, these may reflect perceived mental effort during attention. However, so far no study has verified the possible functional significance of patterns of theta oscillations for SES differences in relation to children's attention.

Given the complexity of the brain processes involved in selective attention tasks, issues still remain regarding the concomitant factors that may explain the observed differences between the SES groups. Few SES studies have assessed possible confounds related to emotional states (e.g., anxiety, nervousness, stress, etc.) and motivational states (e.g., boredom, engagement, etc.). EEG and cortisol measurements alone may not be sufficient to disambiguate the relative functional contributions of the different neural systems. Children's self-reports may add another measure enabling researchers to better discern subtle psychological states associated, on one hand, with the attentional anterior system as reflected by EEG/ERP and, on the other hand, with the HPA axis as reflected by cortisol.

Building on the existing literature and following up to our prior research, the goal of our study was to investigate whether the previously reported midfrontal neural correlates of attention were partly correlated with emotional and motivational variables associated with selective attention. To this end, we examined the pattern of relationships between the neural correlates, cortisol levels, and self-reported affective/motivational states among lower- and higher-SES adolescents. Specifically, we (1) tested differences in neural correlates of selectivity of auditory attention between lower- and higher-SES children; (2) examined patterns of salivary cortisol over a typical school day, including pre- and post-task attention task periods; and (3) established if the observed neural changes were associated with general or task-dependent HPA axis reactivity. As reviewed earlier, lower-SES children seem to attend similarly to both relevant and irrelevant information, therefore, we expected to confirm this tendency in the pattern of the present ERP and EEG power results in relation to the frontal midline scalp sites. Further, we hypothesized that lower SES children would require more effortful control than the higher-SES and might perceive the task more negatively, in particular, as more stressful or more boring. Hence, we expected lower-SES children to show a pattern of (a) relatively greater theta frontal asymmetry, (b) higher cortisol reactivity to the task, and (c) more aversive emotion/motivation self-reports than higher-SES children.

MATERIALS AND METHODS

PARTICIPANTS

Twenty-eight children, all Caucasian, with no hearing impairments, were recruited from two schools in distinctly different socioeconomic neighborhood contexts: one attended and populated predominantly by students with higher SES and the other predominantly by students with lower SES. Since there is only a limited knowledge base, specifically on SES and EEG, it appeared suitable to use the extreme groups approach to enhance the detectability of anticipated effects (see Preacher et al., 2005). Therefore, children were carefully selected to represent non-overlapping SES groups and matched on other relevant characteristics described below. The children were selected from two prospective cohorts in the context of an ongoing larger scale study mapping "neural socioeconomic gradients" in medium-sized urban and rural centers in Western Canada.

To recruit participants, an information package was distributed to all parents whose children attended grade 6 at the two schools. Parents signed a consent form and completed a brief questionnaire on demographic and socioeconomic information about their family including a clause to consent to an extensive follow-up involving saliva and EEG collection. Parents and children each signed consent to disclose school records and grades. Materials explaining what was involved were included in the package and presented at the school to teachers and parents during small information sessions. The recruitment process was carried out in the context of an overarching prospective cohort longitudinal study targeting children from all ages and grades. Thus, only general information about the present study was provided to our target families and children. Hypotheses and purposes of the study were only given (verbally to children and through a written take-home page to parents) at debriefing after the study but not at the recruitment stage. After screening for SES information and school records, the prospective participants were matched on age, gender, ethnicity, grades, health, and "computeracy" (ownership and use of internet and computers, including video gaming). Fifty families were then re-contacted by mail, of which 36 returned signed consents for the present study. Children were given \$5 for their participation, and also received a book of stickers at the end of the study. Written parental informed consent and children's active assent was obtained according to a protocol approved by research ethics boards of all institutions involved.

The final sample of 28 was obtained after exclusion of six participants from the original sample of 36 children; two children (one with higher and one with lower SES) were excluded before running the experimental session as the pre-recruitment questionnaires disclosed paediatric diagnosis of Attention Deficit/Hyperactivity Disorder or Fetal Alcohol Syndrome. Data from another six children were discarded and not submitted to further analysis after preliminary diagnostic analysis: two children (with higher SES) had an insufficient number of artifact-free or artifact-corrected usable EEG data; three children (all with lower SES) did not meet the minimal required behavioural performance threshold; and one (higher-SES) child's salivary cortisol values were not in the reliably readable standard range.

Table 1 summarizes the characteristics of the two groups by parents' and teachers' indications and schools' administrative records, all of which indicated participants who were clinically healthy, typically-developing children with no history of medication or referral to disability assessment or services. In both SES groups, the median of the combined average grades in arithmetic, reading comprehension, and written composition was A− (i.e., ~90%), with no difference in their rank distributions (Mann–Whitney $U = 73.0$, $p > 0.80$). Accordingly, all children in the two groups met expectations on performance in the standard provincial exams assessing their levels of numeracy, reading comprehension, and writing skills (Foundation Skills Assessment, *FSA*, BC Ministry of Education, 2002a,b,c). Although we were not successful in matching children one-to-one within a narrow age range, the groups were reasonably comparable on gender, age, and grade point average (GPA).

SES MEASUREMENT

Socioeconomic information about the parents was first obtained through the brief questionnaire included in the information recruitment package. Items included occupation of parents, their education and income, disposable income, money spent in children's after school activities, clothes and shoes, and money spent on computer/internet items and computeracy. Parents had the option to respond to a category format, where they were presented with a range of values, or to volunteer detailed information such as their specific annual income. Care was taken to include families that lived in single units with unique postal codes. In the second stage of determination of sociodemographic characteristics, children's age, gender, ethnicity, grades, and health were determined directly from the school district database. More exact family income, occupation, and education levels were obtained through linkage of unique postal codes as well as personal identifiers with census data from Statistics Canada (2001). Part of the individual information (i.e., age, gender, ethnicity, and health status) was double checked at the beginning of the experiment through brief in-take verbal questions.

For each student, SES scores were computed using an adapted version of Hollingshead Four-Factor Index of Social Status (Hollingshead et al., 1975; Bornstein et al., 2003) that provided a composite index including residential area quality, as well as parents' income, occupation, and education. Initially, all SES indicator scores were transformed to ranks across individuals so as to equate the rank structure of the four-factor SES categories. Then, the Hollingshead's algorithm was used to weigh and aggregate the measures. Given the collinearity among SES indicators, the composite SES categories or ranks were used in all analysis.

The SES indices of the two groups of children are provided in **Table 1** in raw, ranked, or aggregate forms, depending on the type of measure. The highest occupation of either parent was rated using the Hollingshead categories 9–1, ranging from "higher executives" to "laborers/menial workers." On the composite SES scale (highest = I, lowest = V), the higher-SES parents ranked II (corresponding to college graduates and managers/professionals) whereas the lower-SES parents ranked IV (corresponding to high school graduates and skilled workers) with respective non-overlapping income distributions. The percentage of single parents was 36% in the lower-SES group versus 7% in the higher-SES group. The percentage of unemployed parents was 43% in the lower-SES group versus 0% in the higher-SES group. Parental occupation, education, and family income data were all within the 99% confidence interval of the means for the respective neighborhood data from the most recent available Census data (Statistics Canada, 2001). Therefore, our samples appeared to be representative of the populations of reference, that

Table 1 | Family, neighborhood and demographic characteristics of the two groups of children studied.

	Socioeconomic status		
	High	**Low**	
N[a]	14	14	
Mean age (SD)	12.9 (1.1)	13.7 (1.2)	
Gender (% females)[b]	64	57	
Mean (SD) FSA numeracy percentile score	69.55 (6.39)	57.21 (18.06)	
Mean (SD) FSA reading percentile score	76.85 (9.87)	68.07 (13.15)	
Mean (SD) GPA (year report cards)	2.71 (0.05)	2.67 (0.16)	
PARENTAL SES[d]			
Mean of median household income[c](SD)	70,507.88 (15,369.58)	38,366.83* (21,290.96)	
Mode of self-reported income range	> 90,000	< 30,000	
(%)	(64%)	(43%)	
% Single parents	7	36	
% Parent unemployment	0	43*	
			Max–Min
Mean (SD) occupation	8.29 (1.20)	3.00 (1.11)*	9–1
Mean (SD) education	5.86 (0.95)	2.93 (1.21)*	7–1
Residence rank	7.00	1.00	7–1
Mean (SD) total SES score	87.00 (6.76)	27.79 (6.08)*	
Mean (SD) rank[d]	47.16 (4.62)	11.46 (4.96)*	52.5–3
Composite parent social position class	II	IV	I–V
NEIGHBORHOOD SES[e]			
			(Max–Min rank: 11-1)
% (Rank) Physical vulnerability	3.6 (1)↓	12.4 (9)	
% (Rank) Social vulnerability	3.6 (2)↓	21.0 (10)↑	
% (Rank) Emotional vulnerability	6.1 (3)↓	21.0 (10)↑	
% (Rank) Language/cognitive vulnerability	4.0 (1)↓	26.7 (11)↑	
% (Rank) Communicative vulnerability	2.4 (1)↓	10.5 (9)	
% (Rank) Total vulnerable children[f]	9.6 (1)	43.8 (11)↑	

Note: Significance threshold for multiple comparisons was set at $p < 0.005$ following Bonferroni correction.

[a] *After exclusion of 3 Higher-SES and 5 Lower-SES cases (see text for details).*

[b] *Comparison of aggregate ERP data between females and males within the same SES group did not yield significant differences (see text for details).*

[c] *Canadian Dollars (taken from Statistics Canada, 2001).*

[d] *Computed using a revised version of Hollingshead Four Factor Index of SES (Hollingshead, 1975; Bornstein et al., 2003).*

[e] *from Kershaw et al. (2005).*

[f] *Based on the cumulative number of children manifesting one or more types of EDI vulnerability.*

*$t_{(26)} > 3.98$ $P < 0.001$, *two-tailed.*

"↑ "and "↓ " indicate vulnerability above and below the population mean, respectively, for the study region ($Z > 5.16$, $p < 0.0001$, two tailed).

is, lower- and higher-SES children with no current differences in functional outcomes.

In addition to Hollingshead's residential ranking, quality of residential area (neighborhood) was also defined according to developmental vulnerability estimates taken from Kershaw et al. (2005). The percentage of vulnerable children in the lower-SES neighborhood was 43 vs. 7% in the higher-SES neighborhood. Among 11 geographically incorporated city neighborhoods (population ∼ 65,000), the lower-SES neighborhood ranked 1st (Note: corresponding to *maximum rank* = 11, indicated in ascending rank, a larger percentage) for vulnerability, whereas the higher-SES neighborhood ranked 11th (Note: corresponding to *minimum rank* = 1, indicating in ascending rank, a smaller percentage); in this urban area, the school predominantly attended by lower-SES children was granted *inner-city* school status and as a result received government funding to support various basic intervention programs (e.g., lunch program).

To properly frame our SES data, it is important to briefly mention the socio-geographical context in which the study took place in terms of how the studied neighborhoods compared to, or represented, the reality of the entire province of British Columbia, adding that the present context is not uncommon in Canada. Although the lower-SES neighborhood targeted the lowest average family income and education level in the specific region, the incidence of vulnerabilities in any one aspect of development could be estimated as comparatively small, provincially. Therefore, from the lower-SES population considered, it would be more likely to draw by chance a child that would not show functional issues rather than the contrary.

DESIGN

The experimental protocol is schematized in **Figure 1**. Children were seen individually across an entire ordinary school day. School days were chosen because children's daily routines (i.e., sleep, wake, and mealtimes) have been found to be much more regular than on weekend days (Davis et al., 1999). In addition, the school day appeared to provide the most ecologically valid, relatively controlled setting in which the ERP technique could be coordinated with repeated collection of saliva to evaluate cortisol patterns across the day as well as cortisol responses to the ERP task. To be able to better determine cortisol levels, and distinguish baseline vs. reactivity or recovery after the attention task as well as the global trend within the period of the school day, saliva was collected six times, four times before and two times after the ERP experiment. This choice was informed by the findings of the MacArthur Research Network on Socioeconomic Status and Health (2000). To exclude possible confounds in the cortisol data (food intake, sleep patterns, and intense physical activity), children completed a diary as soon as they arrived at school and after lunch noting when they awoke, type and timing of meals, level and type of physical activity, use of medications and general health during the week in which the study was being conducted.

The EEG recordings during attention testing and three of the saliva collections were conducted in a sound-proof, shielded EEG mobile lab (MUCH, Mobile Unit for Child Health, see D'Angiulli et al., 2005). The other three saliva collections were conducted in a quiet room in each school. The child was escorted in and out of his/her classrooms by one research assistant, to go to the mobile unit and to the quiet room. Pilot work using a virtually identical set-up showed that cortisol samples collected in the mobile lab were comparable to those collected in a quiet room within the school (Nordstokke et al., 2006; Oberlander et al., 2006).

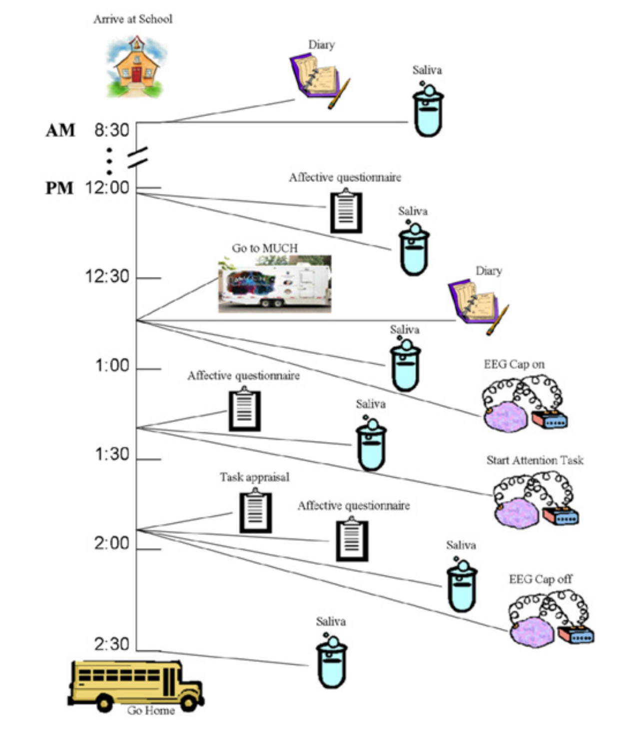

FIGURE 1 | Schematic representation of design and timeline of the study (see text for more details).

EEG/ERP DATA COLLECTION

Stimuli

Before the experiment we ensured that each child had pure-tone thresholds less than or equal to 20 dB HL in the range of 250–8000 Hz in both ears, using a portable Maico Diagnostics air conduction audiometer, model MA 27 (William Demant Holdings, Berlin, Germany).

The experimental stimuli were four pure tones, two frequencies (800 Hz and 1200 Hz) by two durations (100 ms and 250 ms) generated through STIM^2 sound editor function program from Compumedics Neuroscan (Charlotte, NC, USA). Each stimulus tone was framed within a Hanning window of 250 ms with 10% (Rise/Fall of 5 ms) tapered at beginning and end of the tone. The level of the attenuation for both left and right channels were set below 90 dB. EEG was recorded during two blocks (either for 8- or 12-kHz tones) each consisting of 30 (10%) *target-duration tones* (either 100 or 250 ms), 30 (10%) *unattended target-duration tones* with the same duration as the target-duration tones but not the same frequency, 120 (40%) *attended non-target duration tones* with the same frequency as the target tones but not the same duration, and 120 (40%) *unattended non-target duration tones* (distracters) with a different frequency and duration from the target tones (see **Figure 2**).

The four tones were presented binaurally through insert earphones at 84 dB SPL, with an inter-stimulus interval of 1 s. The delivery of the tones was controlled via a Compumedics Audio System interfaced with the STIM^2 program. Stimulus presentation followed different random orders for each block of trials and for each child; the different orders were randomly assigned to a given block and child, except that they were pre-selected so that a target tone would not appear immediately after the next target tone in the presentation sequence. The child was asked to press a button as fast and as accurately as possible to one of the tones (i.e., target), which was designated at the beginning of one of the two recording blocks. Reaction times and accuracy were measured from thumb press on a single button situated in the center of a hand-held response pad.

Data acquisition and recording procedures

The EEG was recorded using EEG Quik caps with silver chloride electrodes (Compumedics Neuroscan., Charlotte, NC, USA). Each participant had seven Ag-AgCl electrode sites (F3, F4, Fz, FC3, FC4, Cz, and Pz) applied according to the 10–20 system of electrode application (Harner and Sannit, 1974) as used previously (e.g., D'Angiulli et al., 2008a), and participated in a modified version of a standard selective attention task (Hillyard et al., 1973; see **Figure 2**). All electrodes were average referenced. Impedances were kept below 5 kOhms. The vertical electrooculograms (VEOG) were recorded from two split bipolar

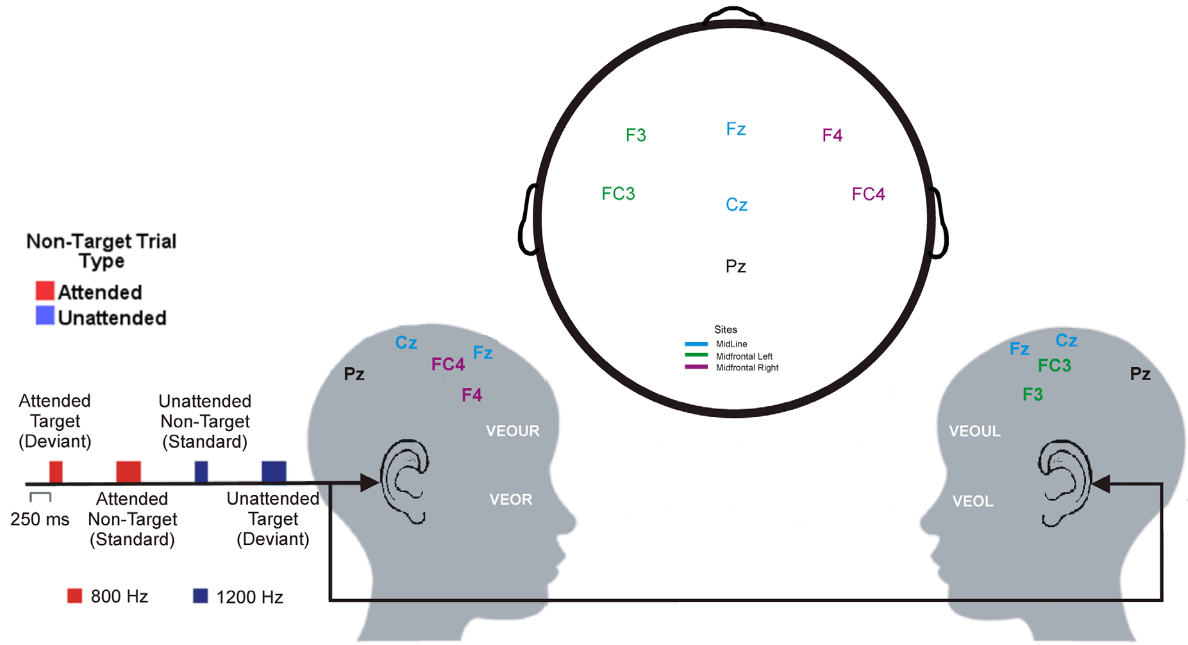

FIGURE 2 | Layout of the auditory selective attention task and electrode positions (adapted from the international 10–20 system of electrode placement) shown from the right side (left picture) and the left side (right picture) of a child's head. As an example, this figure represents a child asked to press a button to the 800-Hz, 250 ms tone (*target* tone). Thus, the *attended* tone was 800-Hz, 100 ms tone (red) and the *unattended* tone was the 1200-Hz, 100 ms tone (blue).

electrodes on the left and right supraorbital ridge (VEOGU, L, and R) as well as the left and right zygomatic arch (VEOG, L, and R). The signal from the electrodes was amplified and digitized by a SynAmps2 and a SCAN™4.3 EEG system (Compumedics Neuroscan, Charlotte, NC, USA) with filter settings at 0.15 Hz (high pass) and 100 Hz (low pass). The data from all channels were digitized online at a sampling rate of 1000 Hz.

EEG data reduction

Ocular artifact reduction was based on the eye movement reduction algorithm devised by Semlitsch et al. (1986). This algorithm consists of constructing an average artifact response and then subtracting it from the EEG channels on a sweep-by-sweep, point-by-point basis. To verify, confirm reliability, and validate our procedure, we correlated our edited data to the data obtained with two additional independently conducted procedures: a manual eye-movement rejection based on visual-score scanning procedure, and the eye-movement correction included in the EEGlab package (Delorme and Makeig, 2004). The agreement between the edited data with our procedure and the two confirmatory procedures was high ($r = 0.87$ with artifact rejection and $r = 0.97$, both $p < 0.0001$).

Initially, we analyzed 5-min resting eyes open/closed EEGs before and after the task, specifically focusing on the alpha band. Since the latter data was explained by individual differences seemingly unrelated to SES or any other dependent measure, we chose not to pursue the analysis of resting EEG further for this paper. However, consistent with our previous research (D'Angiulli et al., 2008a,b), we conducted a spectral power analysis of the single-trial EEG recordings. The focus of the present analysis was on age-appropriate theta and lower alpha (1 and 2) activation concurrent with Nd (encompassing a latency region between 200 and 500 ms), since both are known to vary according to attention, oddball, and working memory operations (e.g., Sauseng et al., 2006, 2010). To determine age-appropriate theta and lower alpha, individual alpha frequency band peaks were first identified and the cut-off point of lower alpha adjusted accordingly in each participant. In this way, theta bands ranged between 3.7 and 6.4 Hz, whereas lower alpha ranged between 6.5 and 9.5 Hz.

The EEG power peak was determined at the median of the waveform distribution corresponding to averages from non-target attended and unattended single trials, which in all frontal electrodes approximated 350 ms, i.e., the common "centering" for all the computed peaks. The extracted peak of the theta band frequency was expressed as percentage change above or below baseline level. *Attentional activation* was operationally defined as reflected by the *difference in theta band power between attended and unattended trials, in non-target ("standard") stimuli*, not requiring response.

EEG band-specific frontal asymmetry continuous values were calculated using the peak power in the theta and lower alpha frequency bands from the averaged attended or unattended single trials in the non-target conditions. Symmetry values were calculated by taking the difference between the natural log of the total peak power recorded from midfrontal left electrodes minus the natural log of the total peak power recorded from midfrontal right electrodes [i.e., $\ln(F3 + FC3) - \ln(F4 + FC4)$]. Asymmetry scores for the unattended data could not be determined since a large proportion of the differences was zero. To obtain a better understanding of the relative distribution of left versus right asymmetry scores between the two SES groups, we also categorized the asymmetry values into two groups of scores. Negative asymmetry scores were categorized as showing relatively greater right hemispheric activation; whereas, positive asymmetry scores were categorized as showing relatively greater left hemispheric asymmetry. This categorization follows conventional assumptions in the literature (Coan and Allen, 2004).

ERP processing

Each participant's EEG was epoched (100 ms pre-stimulus and 900 ms post-stimulus) and averaged with respect to the onset of each tone. Averages were computed for both relevant (i.e., attended) and irrelevant (i.e., unattended) non-target tones, separately for 800 Hz and 1200 Hz. Analyses showed no significant differences as a function of type of pure tone, therefore, the ERPs were averaged across the two types of tones to yield relevant and irrelevant pure tone averages for each participant. Outliers were defined as EEG epochs exceeding $\pm$ 100 μV thresholds and eliminated through automatic artifact rejection. Baseline correction was based on the 100 ms pre-stimulus interval.

The effect of selective attention in the ERPs was operationalized by computing negative difference waveforms as in previous work in children of comparable ages (Loiselle et al., 1980; Berman and Friedman, 1995; Bartgis et al., 2003). ERP differences between *attended tones (same frequency but different duration compared to the target tone)* and *unattended tones (different frequency and duration compared to the target tone)* were calculated. (Note that these trials did not require manual responses). Amplitudes of the attention-related *difference negativity* (*Nd*) wave were calculated as the maximum negative deflection at the 200–500 ms interval in the ERP difference waveforms between attended and unattended target tones.

CORTISOL SAMPLING

The daytime cortisol pattern was determined from saliva samples collected over the course of the school day, before (8:20 am, 12:15 pm, 12:45 pm, and 13:15 pm) and after (13:45 pm and 2:45 pm) the ERP session and completion of the attention task. To collect saliva, the child was asked to spit into a small plastic test tube. Saliva samples were stored at 4°C until sampling was completed. The samples were then brought to the laboratory, where they were stored at −20°C until assayed. All samples from any one participant were included in the same batch to eliminate within subject inter-assay variability. Samples were assayed by radioimmunoassay using the Salimetrics High Sensitivity Salivary Cortisol Enzyme Immunoassay Kit (Salimetrics LLC, Philadelphia, PA). All samples were assayed in duplicate, and duplicates varying by more than 20% were re-assayed. The inter-assay and intra-assay variation were 3.04 and 6.58%, respectively.

The first saliva sample was taken within a few minutes after arrival at school (8:20 am). Four samples were taken after lunch (lunch period was from 11:45 am to 12:30 pm, the day previous to the scheduled experiment time parents were reminded that children needed to avoid consuming food or drink that could interfere with cortisol, e.g., dairy products) at approximately 30 min intervals [12:15 pm (actual M = 12:16, SD = 0.04); 12:45 pm (actual M = 12:47, SD = 0.02); 13:15 pm (actual M = 13:17 SD = 0.01); 13:45 pm (actual M = 13:47, SD = 0.01)]. Of the post-lunch samples, the first two were obtained to evaluate cortisol changes due to the EEG capping procedure and the subjective experience of the experimental session, as reported in previous neuroimaging studies (e.g., Tessner et al., 2006). To determine cortisol responses pre- vs. post-ERP testing, the target samples were those collected at 13:15 pm, immediately before starting the attention task, and at 1:45 pm, immediately after completion of the task. The ERP session lasted 30 min. Saliva was also obtained before the children went home (14:45 pm) to measure possible differences between lower- and higher-SES groups in returning to baseline (recovery) after the ERP session, as well as to assess more fully the expected decrease in cortisol levels over the school day.

In addition to school day cortisol, we derived an index of *task reactivity* by calculating the percent of change in post-task cortisol levels as compared to baseline, namely as:

$$[(\text{baseline level} - \text{post-task level}/\text{baseline level}) \times 100]$$

As baseline cortisol level, we selected the second cortisol sample, collected in the school at 12:15 pm, 30 min before going to the mobile lab and starting the task. Thus, the task reactivity could be assumed as most likely reflecting the changes in children's cortisol occurring in relation to what happened specifically during our attention task, as opposed to *general reactivity* (i.e., participating in the experiment). To distinguish general reactivity from task reactivity we calculated a further index measuring the percent change in pre-task cortisol levels as compared to baseline.

$$[(\text{baseline level} - \text{pre-task level}/\text{baseline level}) \times 100]$$

We used the same baseline measure used to obtain the task reactivity index; however, as pre-task cortisol level, we selected the fourth cortisol sample, collected at the start of the attention task after children had spent time wearing the EEG cap.

Cortisol data were examined for outliers, defined as any value more than ±3 SD from the mean (Gunnar et al., 1989; Ramsay and Lewis, 2003). Two children had outlier values for cortisol. These values were "winsorized" following the method of Tukey (1997), which involved replacing the outlier value with the closest value within the 3 SD range, and then included in the data analyses.

EMOTIONAL STATE AND TASK APPRAISAL QUESTIONNAIRES

Before and after the attention task, the children completed a five-point rating scale measuring multiple affective states, containing eight age-appropriate items adapted from a standard *affective questionnaire* (Usala and Hertzog, 1989) (see Appendix A), and a post-test *task appraisal questionnaire* (Tomaka et al., 1999) (see Appendix B). Both types of items were pre-selected from the much larger sets included in the original sources based on previous extensive pilot work (D'Angiulli et al., 2007). Through the task appraisal questionnaire, children self-rated their perceived levels of engagement, difficulty, stress, fear, and coping attributed to the attention task. The affective questionnaire was administered three times, one at 12:15 (pre-test 1) to control for anticipatory reactive states, immediately before the ERP session at 13:15 (pre-test 2), and at 13:45 (post-test) upon completion of the ERP session. The task appraisal questionnaire was administered immediately after the post-test affective questionnaire. The collection times are shown in relation to the entire design of the study in **Figure 1**.

ANALYTIC STRATEGY

In all analyses, we used GLM through either ANOVAs, focused contrasts, or multiple regressions. Repeated measures ANOVA models used Greenhouse–Geisser adjustment. Bonferroni correction was used to adjust for multiple comparisons. Analyses were based on valid standard trials (i.e., correctly withheld responses). The rationale for our analyses strictly followed the predictions linked to the hypotheses put forward in the introduction.

Initially, we conducted preliminary analyses showing that differences between the SES groups were not associated with group confounds in accuracy or reaction times (given that the task had been pre-calibrated to keep all children at approximately the same performance level).

We then tested the prediction that the higher-SES group would show a greater ERP differentiation between attended (relevant) and unattended (irrelevant) tones than the lower-SES group. For consistency with previous results, all electrodes were analyzed individually to establish the effect sizes associated with the Nds for each electrode, split by SES group. Successively, the individual electrodes were included as separate levels in a 2 (Group: lower-SES and higher-SES) × 7 (Electrode placement: PZ, CZ, FC3, FC4, F3, FZ, and F4) ANOVA.

Following this preliminary ERP analysis, the different electrodes were aggregated (i.e., EEG signal was collapsed over electrodes by averaging) to reflect coarsely the main subdivision of the attentional networks (Posner and Rothbart, 2007). That is, the analysis focused specifically on four groups of electrodes: *parietal* (PZ), corresponding to the posterior attention system, *midline* (CZ and FZ), *midfrontal left* (F3 and FC3) and *midfrontal right* (F4 and FC4), corresponding to the main parts of the anterior attention system. Thus, to test the hypothesis that lower SES children attended and monitored irrelevant stimuli significantly more than their higher SES counterparts, over the two frequency bands, we ran a 2 (Frequency Band: theta vs. lower alpha) × 4 (Electrode Group) × 2 (SES Group) ANOVA with Attentional Activation Difference as the dependent variable.

Furthermore, we assessed whether:

1. Any event-related power asymmetry effects were present, to test the hypothesis of left hypo-activity during the attention task,
2. The two groups differed globally in cortisol when examined during their school day, including before and after the attention task,
3. Pre-selected self-rated emotional and motivational state items differed in the two groups before and after the task, and the two SES groups differed for emotional states associated with task appraisal (e.g., difficulty, stressfulness etc.)

All these analyses used simple or polynomial contrasts based on ANOVA models.

Based on the literature, we expected very large individual differences in cortisol changes capable of overshadowing group effects, especially given our modest sample size. Analysis of individuals in the groups is, in cases such as the present one, a very valuable tool to detect subtle differences in mechanisms that may have important functional implications for neurobiological processes (Kosslyn et al., 2002). Therefore, the final stage of our analysis focused on the hypothesis that individual variations in greater attentional activation changes in theta power for the right midfrontal electrodes would be associated with individual variations in SES rank, task-dependent HPA axis reactivity, and motivational changes measured at the beginning of the task (also expressed as percentage change from pre-task baseline) but not with individual variations in general HPA axis reactivity. This hypothesized pattern of relationships was assessed through a single multiple regression model in which the predictors were entered serially as separate blocks (in the same order as above) so we could assess the relative contribution of each variable.

RESULTS

BEHAVIOURAL

Reaction times, accuracies, and false alarms did not differ significantly between lower- and higher-SES children across different stimulus conditions (**Table 2**). The overall average performance accuracy was over 80% and false alarms were below 5%. This also reflected individual differences as the individual accuracy was over 75% and below 90%, indicating the attention task difficulty level was moderately easy, yet not at ceiling. Overall the groups displayed similar behavioural response levels which, therefore, cannot account the differences in the EEG/ERP patterns. Collapsed across groups, correlations between aggregate mean ERP amplitude and accuracy or RTs for hits and false alarms yielded small effects ($0.08 \leq r \leq -0.17$, $p's > 0.42$).

Table 2 | Behavioural profiles (and statistical comparisons) of the two groups of children in relation to the auditory selective attention task (responses to deviant attended tones).

	Socioeconomic status			
	High ($n = 14$)	**Low ($n = 14$)**	$t_{(26)}$	***P***
ACCURACY %				
Hits	84.52 (11.92)	80.48 (19.45)	0.66	0.51
False alarms	3.38 (4.43)	4.88 (5.90)	−0.76	0.45
REACTION TIME IN MS				
Hits	569.84 (50.82)	571.64 (57.93)	−0.09	0.93
False alarms	506.72 (71.26)	501.38 (71.04)	−0.19	0.84

Note: Values represent group means (values in parentheses represent standard deviations) collapsed across tone frequency conditions which did not reveal significant differences on preliminary analyses. Accuracy is in percentage; reaction times are in milliseconds.

EEG/ERP

Negative wave differences

Figure 3A and **3B** shows waveforms and Nd amplitudes for higher and lower-SES groups, respectively, for attended and unattended standard stimuli. **Figure 3C** shows the central outcome of the observed Nds. A mixed-model ANOVA, Electrode (7 levels) × SES Group (2 levels), revealed no interaction ($F < 1$) and an effect of SES Group [$F_{(1, 26)} = 6.79$, MSE = 354.98, $p = 0.01$, $\eta_p^2 = 0.21$] indicating that the Nd amplitudes were more negative for higher- than lower-SES children (*median of mean Nds*: 6.81 μV). However, there were also differences between electrodes [$F_{(1, 76)} = 3.23$, MSE = 30.85, $p < 0.05$, $\eta_p^2 = 0.11$]. A follow-up polynomial contrast showed that the pattern in **Figure 3C** is well described by a quadratic trend [$F_{(1, 26)} = 6.83$, MSE = 18.14, $p = 0.01$, $\eta_p^2 = 0.21$] indicating a larger Nd in the midfrontal electrodes. Since the pattern of

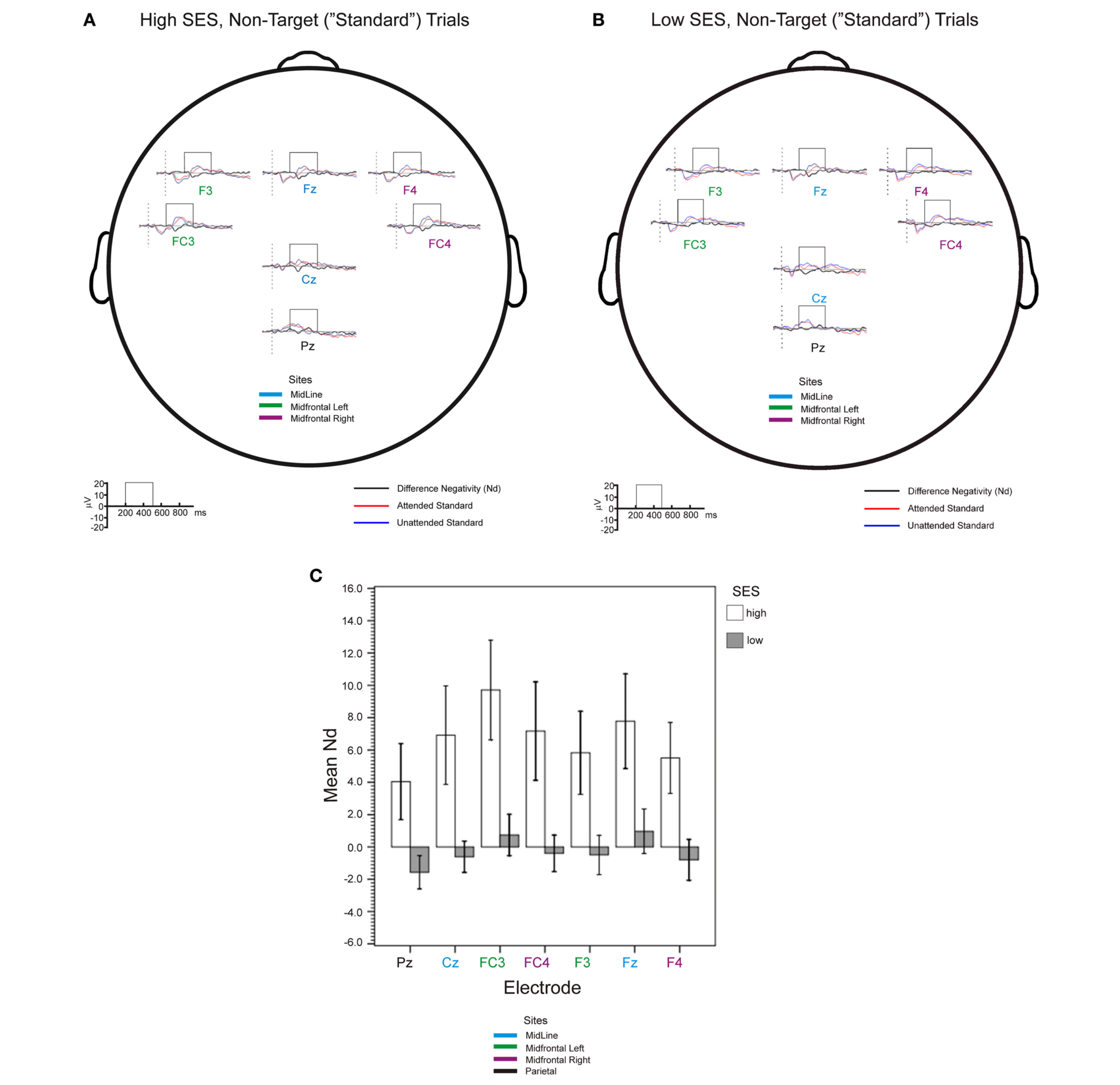

FIGURE 3 | Group-mean event-related potentials (0–30 Hz) for the high-SES (A) and low-SES (B) children, averaged with respect to attended (red) and unattended (blue) tones are shown for high and low SES children at all tested electrode sites. Difference evoked waveforms (attended - unattended) are shown below the standard waveforms in black. **(C)** Central outcome of mean difference negativity (Nd) analysis (see windows in panels **A** and **B**); error bars represent ± 1 SE.

results was consistent with aggregating the electrodes, to test more focused hypotheses about the anterior attention system, we ran an Electrode Group (parietal, midline, midfrontal left, midfrontal right) × SES Group ANOVA. The results for main effects were virtually identical to the analysis on all electrodes, but Bonferroni pairwise comparisons clearly confirmed that, although the Nds were of similar magnitude at midline and midfrontal left electrodes, they were also significantly ($p < 0.05$) larger than Nds at parietal and midfrontal right electrodes.

There were no significant differences associated with gender within either SES group or when the two SES groups were collapsed. Furthermore, there were no significant interactions between Gender and SES when the ANOVA model included Gender as another factor.

Event-related EEG band power differences

We compared mean theta peaks for all electrodes in attended and unattended conditions in the two SES groups; the comparison is shown in **Figure 4A**. We found a three-way interaction between Group, Electrode Placement and Attention Condition [$F_{(1, 26)} = 3.44$, MSE $= 235.79$, $p < 0.05$, $\eta_p^2 = 0.13$] and a two-way interaction between Group and Attention Condition [$F_{(1, 26)} = 7.36$, MSE $= 235.79$, $p < 0.05$, $\eta_p^2 = 0.25$], as well as a main effect of Electrode Placement [$F_{(1, 26)} = 2.93$, MSE $= 235.79$, $p < 0.05$, $\eta_p^2 = 0.12$]. For all sites but PZ, there was a cross over interaction in which higher-SES children showed higher power level for attended than for unattended trials, whereas the lower-SES children showed the opposite pattern. Repeating the analysis without the PZ data, both three-way interaction and Electrode Placement effects vanished, confirming the crossover effect of Group by Attention Condition for all frontal sites [$F_{(1, 26)} = 8.38$, MSE $= 218.23$, $p < 0.01$, $\eta_p^2 = 0.27$]. Thus, other additional neural processes were associated with attending to irrelevant tones, in lower-SES children.

Figure 4B shows the difference in EEG power change in relation to attended vs. unattended trials (Attentional Activation) for theta and lower alpha bands over the aggregated electrodes in the two SES groups. Again, a three-way interaction Frequency Band × Aggregated Electrodes × SES Group ceased to be significant once the parietal site was excluded from the ANOVA model. A main effect of frequency band showed that theta showed ∼21% more overall attentional activation than lower alpha [$F_{(1, 26)} = 13.99$, MSE $= 1051.04$, $p < 0.001$, $\eta_p^2 = 0.40$]. There was also an interaction between Frequency Band and SES Group [$F_{(1, 26)} = 7.41$, MSE $= 1051.04$, $p < 0.05$, $\eta_p^2 = 0.26$] and a main effect of SES Group [$F_{(1, 26)} = 9.37$, MSE $= 562.39$, $p < 0.01$, $\eta_p^2 = 0.31$]. This pattern of results could mainly be explained by the effect of SES Group significance for the theta [$F_{(1, 26)} = 8.38$; MSE $= 1961.81$, $P < 0.01$] but not for the lower alpha data ($F < 1$).

Frontal theta asymmetry and SES group

For the theta band, lower-SES children showed a marked right activation asymmetry whereas higher-SES showed the opposite pattern [$t_{(26)} = 2.21$, $p < 0.05$], see **Figure 5A**. As shown earlier (i.e., **Figure 4B**), lower alpha decreased globally as theta increased; because of this well-documented overall inverse relation, characteristic of event-related power [see review in Klimesch (1999)], we did not find any significant asymmetry for the lower

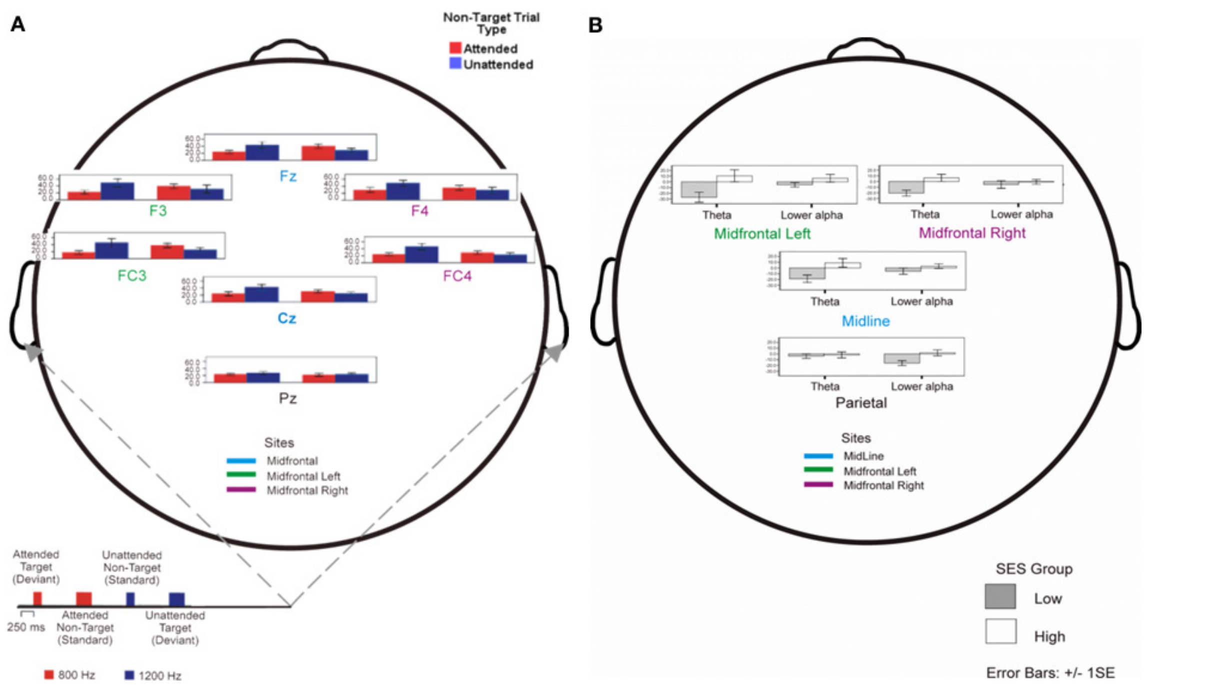

FIGURE 4 | (A) Group-mean event-related theta (3.7–6.4 Hz) power of single trial data (non-target tones) averaged with respect to attended (red) and unattended (blue) tones are shown for high and low SES children. **(B)** Attended vs. unattended EEG Power peak percentage change over baseline in standard trials (attentional activation) for theta and lower alpha frequency bands.

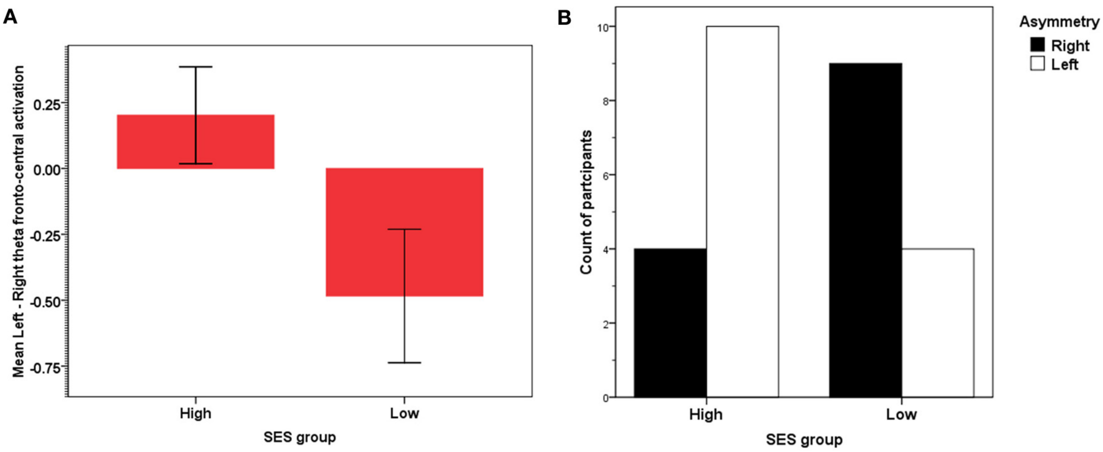

FIGURE 5 | (A) Frontal asymmetry in theta activation in high- and low-SES children. **(B)** Relative frequency distribution of right vs. left frontal theta asymmetry in high- and low-SES children.

alpha [$t_{(26)} < 1$]. When we compared the relative distribution of left vs. right asymmetry categorical scores between the two SES groups for theta, a significant difference was found between the two SES groups' distributions of participants showing left vs. right activation [$\chi^2_{(1)} = 4.46$, $p < 0.05$]. More individuals in the lower-SES group had relatively greater right than left activation (64 vs. 36%, $Z = -2.18$, $p < 0.05$), whereas in the higher-SES group, more individuals had relatively greater left than right (71 vs. 29%, $Z = -3.46$, $p < 0.001$) activation (see **Figure 5B**).

QUESTIONNAIRE DATA

In relation to self-rated emotional/motivational states, there were no significant changes from pre- to post-test except, importantly, for the *bored* item [$F_{(1, 26)} = 9.03$, MSE = 0.32, $p < 0.01$, $\eta^2_p = 0.27$]. Children's self-reported boredom declined from 12:15 pm (Pre-test 1) to 13:15 pm (Pre-test 2) but returned to initial values at 13:45 pm (Post-test). There were however no differences between the two SES groups.

The task appraisal data showed no reliable differences between the SES groups. In addition, both SES groups reported significantly higher ratings for stress induced by the task as compared to stress as an internal affective state [mean task appraisal: 2.14 (SD = 1.24) vs. mean affective state: 1.36 (0.68); $F_{(1, 26)} = 8.57$, MSE = 1.01, $p < 0.01$, $\eta^2_p = 0.25$], suggesting that the task was mildly stressful.

CORTISOL DATA

A mixed-design ANOVA, 2 (SES) × 6 (Collection Time for cortisol), was computed with repeated measures on Collection Time. There was a main effect of Collection Time [$F_{(2, 52)} = 4.95$, MSE = 0.19, $p < 0.01$, $\mu^2_p = 0.19$] and an effect of SES [$F_{(1, 25)} = 3.57$, MSE = 0.04, $p < 0.05$, $\mu^2_p = 0.12$], but no interaction effect ($F < 1$). Overall, cortisol levels in lower-SES children were marginally higher than levels in higher-SES children. However, the two groups displayed a similar pattern of cortisol secretion over the school day, with highest levels in the morning, and levels progressively declining over the day [$F_{(1, 25)} = 5.60$, MSE = 0.03, $p < 0.05$, $\mu^2_p = 0.18$].

The index of task cortisol reactivity we used (see analytic strategy section) showed a mean change of 29.23 and 26.80% in the lower and higher SES group, respectively. In contrast, general reactivity showed a mean change of 0.93 and 26.80% in the lower and higher SES groups, respectively. For both groups and for both reactivity types the inter-individual variability was very large (in all cases, standard errors were between 22–23%). Thus, we could not detect any significant SES differences in reactivity. Although in the right direction as we expected, the differences between the groups were basically washed out by inter-individual variation, this means that given our very modest sample size, one way to detect genuine differences associated with SES was to use a regression approach focusing on individual differences effects. This was pursued in the next analysis.

RIGHT MIDFRONTAL THETA POWER, SES RANK, POST-TASK CORTISOL REACTIVITY, AND BOREDOM

We built a multiple regression model to test the hypothesis that individual variation in theta attentional activation at the midfrontal right electrodes would be predicted by individual variation in SES, changes in motivational state at the beginning of the task as reflected by self-rated boredom (the only questionnaire item which in the other analysis yielded reliable significant effects in relation to task time-course), and reactivity specific to our attention task, as opposed to individual variation in general reactivity. The results of this analysis are shown in **Table 3**. The gradient of midfrontal right attentional activation was associated with individual differences across SES rank, task reactivity, and increase in boredom from baseline to onset of the task. When general reactivity was included in the model, its effects were null, while including task reactivity significantly added explained variance to the model.

Correlations among SES rank, task reactivity, and boredom increase ranged from −0.06 to 0.06, which rules out multicollinearity artifacts.

Table 3 | Results of multiple regression models examining relationships between individual variation in theta attentional activation in midfrontal right sites and individual variation in cortisol reactivity and boredom increase in relation to the attention task.

					Change statistics				
Model	**R**	**R square**	**Adjusted R square**	**Std. error of the estimate**	**R square change**	**F change**	**df1**	**df2**	**Sig. F change**
MODEL SUMMARY									
1	0.532[a]	0.283	0.251	21.453	0.283	8.693	1	26	0.003
2	0.658[b]	0.432	0.378	19.540	0.149	5.518	1	25	0.013
3	0.737[c]	0.543	0.475	17.958	0.111	4.862	1	24	0.018
4	0.743[d]	0.552	0.458	18.247	0.009	0.372	1	23	0.534

[a] *Predictors: (Constant), SES Rank.*

[b] *Predictors: (Constant), SES Rank, Task Reactivity.*

[c] *Predictors: (Constant), SES Rank, Task Reactivity, Boredom Change.*

[d] *Predictors: (Constant), SES Rank, Task Reactivity, Boredom Change, General Reactivity.*

	Model	**Unstandardized coefficients**		**Standardized coefficients**	**T**	**Sig.**
		B	**Std. Error**	**Beta**		
COEFFICIENTS[a]						
1	(Constant)	−28.475	9.121		−3.122	0.005
	SES rank	0.724	0.246	0.532	2.948	0.008
2	(Constant)	−27.086	8.329		−3.252	0.004
	SES rank	0.691	0.224	0.508	3.082	0.006
	Task reactivity	0.177	0.075	0.387	2.349	0.030
3	(Constant)	−27.714	7.660		−3.618	0.002
	SES rank	0.714	0.206	0.525	3.462	0.002
	Task reactivity	0.186	0.069	0.406	2.678	0.015
	Boredom change	0.139	0.063	0.334	2.205	0.039
4	(Constant)	−29.780	8.488		−3.509	0.002
	SES rank	0.740	0.214	0.544	3.461	0.003
	Task reactivity	0.254	0.131	0.554	1.929	0.065
	Boredom change	0.156	0.070	0.377	2.229	0.038
	General reactivity	−0.052	0.086	−0.180	−0.610	0.326

[a] *Dependent variable: theta midfrontal right activation.*

DISCUSSION

This study examined the relationships among EEG correlates of attentional processes, salivary cortisol levels and emotional states in two groups of adolescent children representing the opposite ends of the SES spectrum. Consistent with previous results and some of our hypotheses, we found that the higher-SES group showed a greater ERP differentiation between attended (relevant) and unattended (irrelevant) distracters in midline electrodes. EEG power analysis showed that of those frequency bands analyzed, the most important results were found for theta. In particular, there was a crossover interaction between SES group and attention condition on theta peak power: lower-SES participants showed significantly higher power when ignoring tones rather than attending to them, whereas, higher-SES participants showed higher power when attending to tones rather than ignoring them. One possible interpretation is that, due to the fact that they live in less predictable and more threatening environments, lower-SES children may have learned the tendency to attenuate attentional selectivity, allocating relatively greater attention to distracters. However, to perform like their higher-SES counterparts they would also need to exert more effortful control. Thus, presumably the observed EEG/ERP pattern of results may reflect this background of differential processing "preference" (D'Angiulli et al., 2012) which the lower-SES children brought with them into the task.

EEG frontal asymmetries were also compared. In the attended channel, a significant difference between SES groups was found in the distribution of participants showing left vs. right frontal theta activation: This result is consistent with the finding of hypo-activity of the left frontal areas in lower-SES adolescents reported in another study Tomarken et al. (2004). The finding of left hypo-activity, however, in our case invites an interpretation that is quite different from the one proposed by Tomarken and colleagues (who linked hypo-activity to depression and psychopathology). First our effects were observed not on resting EEG but on event-related activity power; and second, those effects were observed in a sample of children with no known mental health problems or psychopathology or comorbidities, the children differed mostly on the environment in which they lived. Thus, our analysis revealed significant individual variations in the increase of selective attention in the two SES groups: Theta power difference increased with SES and involved right midfrontal electrodes. Since theta increased in the expected inverse fashion relative to lower alpha (Klimesch, 1999), our data are genuine evidence of event-related asymmetry, as theta asymmetry is exactly what would be expected when no reliable differences would be detectable for alpha (i.e., because of floor effects). Furthermore, we controlled for the most important confounds: motor requirements/response demands and task difficulty (see Andreassi, 2000; Cacioppo et al., 2000) by considering only standard (non-target) trials requiring no response, and counterbalancing the different tone features (frequency and duration). Thus, our results are not only reliable, but also novel, since to our knowledge this is the first study on event-related asymmetry focusing on SES influences in children. Given the link between attention deployment and subjective perception of mental effort (e.g., Pribram and McGuinness, 1977, 1991; Howells et al., 2010), the broader psychological/functional implication is that the frontal asymmetry differences observed in the theta band in lower SES children reflect level of perceived mental effort during the selective attention task.

We also found group differences in overall cortisol levels and an association between individual variation in EEG power and task-dependent HPA reactivity, associated with individual SES rank and an increase in boredom at the start of the task. However, SES did not predict either boredom or cortisol reactivity to task. In addition, the regression models indicated that SES remained a significant predictor of theta power even after controlling for boredom and reactivity, suggesting independent effects. These results do not seem to support the hypothesis that either perceived stress or boredom related to the task was confounded with frontal cognitive functions. Instead, our findings seems to suggest that SES effects were independent of task engagement or perceived stress and SES effects on frontal functions may be independent of these measures. One novel contribution of our study was to present data controlling for motivational aspects and perceived stress during a cognitive task, this type of data can better inform interpretation of frontal EEG or ERP results in SES research eliminating the possibility of confounds (Jolles and Crone, 2012). Indeed, our results confirm that it is unlikely that previous ERP/EEG findings concerning SES effects on selective attention could be attributed to confound due to the variables considered here.

Our cortisol results provide some evidence that the brain areas implicated are part of the anterior attention system. With the results from the power analysis, the finding of differential patterns of relationship between selective attention and cortisol reactivity suggests that lower-SES children may have used more executive resources to control for the processing of (and response inhibition to) irrelevant information than did the higher-SES children. Importantly, as noted, components of the anterior attentional system are believed to be involved in the regulation of reactive, emotion-related systems, such as the HPA axis (see Davis et al., 2002; Blair et al., 2005). From the point of view of developmental psychobiology, these differences in neural processes in lower- and higher-SES do not necessarily imply a behavioural performance gap, but may instead be interpreted as part of different coping or even motivational responses enabling children to adapt to environments which present different types of information-processing challenges. Given that lower- and higher-SES children live in very different environments, these two groups might develop experience-dependent patterns of neural activity and self-regulation that would be differentially and preferentially associated with selective variations in attention and executive processes to differentially match the types of environmental challenges they most frequently encounter (Blair, 2010). It would have to be seen whether and which functional consequences could be associated with SES influence in more difficult tasks than ours, in which overall behavioural performance is not above 80%. This is an important empirical question for future research.

The purpose of the present study was to isolate the effect of SES under the assumption [well supported by the literature, see review by D'Angiulli et al. (2012)] that SES is a proxy of social-environmental conditions that are known to influence development quite substantially and, therefore, to focus on one specific task that we hypothesized to be independent from prior physical and mental health conditions, academic achievement or cognitive outcomes. As shown by the broad literature on cognitive performance, school achievement, physical, and mental health, outcomes are often consequences of exposures to unfavorable environments which tend to correlate with lower SES. Without controlling for the contribution of those consequences from our analysis, it would not be possible to make inferences about the role of SES on the processes of interest. In other words, if there was variation in the sample in terms of physical and mental health, cognitive performance, and school achievement, we would be in no position to infer that the differences we found between the groups were indeed associated with SES environment rather than other factors such as health and cognitive skills. Consequently, the matched design we used is accepted as a rigorous method to account for the effect of known confounders (Jackson and Verberg, 2006). In addition, as the current sample is drawn from a larger study, the epidemiological background data of the geographical context in which our study was conducted (Kershaw et al., 2005) show that the lower-SES sampling distribution of reference is a variegated one in which drawing non-vulnerable cases should actually be more likely (specifically, $P = 0.66$) than drawing vulnerable ones. Hence, far from representing a form of bias, and given our scope, the sample matching we used insured "translation validity" (Trochim, 2000). Still, our sample-matched design leaves open the empirical question of what would the pattern of findings look like had we used the alternative design (i.e., unmatched SES samples).

In conclusion, we found ERP differences between lower- and higher-SES children *without* differences in their concurrent behavioural performance. EEG power analysis suggests that children from the two groups recruited different neural processes to obtain similar behavioural performance levels. Relative to higher-SES children, lower-SES children engaged resources to also attend to irrelevant auditory information.

The individual differences relationship between SES, cortisol reactivity, and frontal activation suggests that lower-SES children used additional compensatory resources to monitor/control response inhibition to distracters, perceiving also more mental effort (reflected by theta asymmetry) as compared to the higher-SES children. In spite of this, perceived stress and boredom related to the task were not related to SES effects. Consequently, this study draws attention to the importance of considering variables related to self-regulation and motivation to control for possible subtle confounds but in the end confirms that the midfrontal mechanisms most responsible for the SES effects on children's selective attention reported here and in previous studies reflect genuine cognitive differences.

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APPENDIX A

AFFECTIVE QUESTIONNAIRE

Pre-testing

What are you feeling right now?						
Proud	1 not at all	2	3 somewhat	4	5 very much	I don't understand this question
Ashamed	1 not at all	2	3 somewhat	4	5 very much	I don't understand this question
Nervous	1 not at all	2	3 somewhat	4	5 very much	I don't understand this question
Relaxed	1 not at all	2	3 somewhat	4	5 very much	I don't understand this question
Angry	1 not at all	2	3 somewhat	4	5 very much	I don't understand this question
Bored	1 not at all	2	3 somewhat	4	5 very much	I don't understand this question
Stressed	1 not at all	2	3 somewhat	4	5 very much	I don't understand this question
Overwhelmed	1 not at all	2	3 somewhat	4	5 very much	I don't understand this question

Proud—You are pleased at yourself, (The parents were proud that their child was a hero).
Ashamed—shame, guilt, disgrace (I was ashamed of my behavior, I know that I should not have acted that way).
Nervous—timid, fearful (I felt nervous when I had to give a speech in front of my school).
Relaxed—become loose, less tense (I always feel relaxed when I am lying on the beach).
Angry—Displeasure (I was very angry when my friend broke my favourite toy).
Stressed—physical or emotional (I feel stressed when I don't have enough time to finish my test).
Overwhelmed—Sometimes if too much is going on all at once, I don't want to be involved anymore, I want to get away or hide in a quiet place.

APPENDIX B

TASK APPRAISAL QUESTIONNAIRE

Post-testing

1. How did you feel during the task?						
Eager	1 not at all	2	3 Somewhat	4	5 very much	I don't understand this question
Nervous	1 not at all	2	3 Somewhat	4	5 very much	I don't understand this question
Confident	1 not at all	2	3 Somewhat	4	5 very much	I don't understand this question
Bored	1 not at all	2	3 Somewhat	4	5 very much	I don't understand this question
2. How stressful was the task?	1 not at all	2	3 Somewhat	4	5 very much	I don't understand this question
3. How well were you able to do the task?	1 not at all	2	3 Somewhat	4	5 very much	I don't understand this question
4. How difficult was the task?	1 not at all	2	3 Somewhat	4	5 very much	I don't understand this question
5. How scary/intimidating was the task?	1 not at all	2	3 Somewhat	4	5 very much	I don't understand this question

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OPINION ARTICLE
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Improving research of children using a rights-based approach: a case study of some psychological research about socioeconomic status

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INTRODUCTION

Socioeconomic status (SES) and other social determinants of health are "identified as top priorities for action" in research [Canadian Coalition for the Rights of Children (CCRC), 2011, p. 42]. Consequently, SES is increasingly popular in some psychological and neuroscience research in order to expand upon understanding of its relationship to child development. In sum, this research demonstrates: "Growing up in a family with low SES is associated with substantially worse health and impaired psychological well-being, and impaired cognitive and emotional development throughout the lifespan" (Hackman et al., 2010, p. 651). Expanding the SES focus to include consideration of child rights (CR) in the research process, structure, and results would advance better understanding of children and improve research about them.

This brief article inquires: how would CR assist research about children by psychologists interested in neuroscience and SES? In short, children have human rights, which involve "the right to be properly researched" (Knowing Children, 2010). Indeed, Steinmetz (2010), p. 12 states that all our knowledge about how "abnormal child development" adversely affects the child's brain structure and capacity can be ultimately traced back to the disrespect of his/her rights. As such, CR should inform efforts related to researching the relationship between SES and neuroscience.

This brief commentary recognizes SES includes "occupations and thus the underlying levels of education and resulting incomes of the adult members of a household" (Johnson et al., 2007, p. 526). First, this article describes a child RBA (CRBA). Then, a CRBA frames analysis of some recent neuroscience and SES research and review articles before concluding.

WHAT IS A CRBA?

Child rights are outlined in various legal instruments but essentially elaborated in the Convention on the Rights of the Child (CRC), adopted by the United Nations, (1989). The CRC has 193 States Parties (UN Treaty Collection, 2011), more than any other international rights treaty. It defines a child as anyone under 18 years and enunciates civil, political, economic, social, and cultural rights. The UN Committee on the Rights of the Child (1991, III) has identified four CRC provisions as general principles that inform implementation: non-discrimination, best interests, survival and development, and views of the child/participation. CR are fundamentally important and have revolutionized understanding about children.

Child rights influence all processes concerning children (Collins, 2008) and provide a framework in a CRBA to analyze populations and situations. A CRBA is important in (Collins, 2007) *inter alia* advancing respect, allowing measurement of progress, and improving effectiveness and sustainability of efforts (United Nations and OHCHR, 1989; Chinkin, 2001).

Yet, most researchers inadequately consider CR upon their efforts and results (Collins, 2007). While psychologists have made significant contributions to better understanding about children, room for progress remains in neuroscience research. For example, a recent review does not identify CRBA as a future direction (Hackman and Farah, 2009, p. 69).

HOW CAN CRBA IMPROVE RESEARCH?

Child rights are relevant to research about children in at least two ways. First, CR highlight the importance and nature of the evidence base, which should be accurate without bias, reflect context, and respect the subjects. Second, as CR regulate relationships (Pearson, 2012) in terms of how children should be respected, researchers should consider their relationships to children they study. Researchers may be well-meaning in attempting to capture child needs, but efforts may not respect his/her rights. For example, researchers across disciplines commonly question: "What is a child?" (i.e., Schapiro, 1999; Stainton Rogers, 2003). From a rights-based perspective, this question should be reframed as: "who is a child?" to support understanding of the child as a subject, not an object (Van Bueren, 1998), and influence research and analysis.

In practice, a CRBA can be guided by the aforementioned CRC's four guiding principles (Collins, 2007) to support research and improve understanding of children. To illustrate, these principles now guide discussion about how a CRBA has and must influence neuroscience research.

A CRBA TO RESEARCH

NON-DISCRIMINATION

Convention on the Rights of the Child a.2 outlines CR shall not be hindered by discrimination on various grounds. Consequently, this principle demands consideration of every child and his/her group identity(ies) to prevent exclusion or marginalization in research (Collins, 2007) with appropriate data disaggregation to highlight discrimination.

Accordingly, some researchers recognize the diversity of children in their work but improvements are generally needed to advance non-discrimination. For instance, Lovejoy et al. (2000), p. 572 categorize all children in their meta-analysis about parenting into only three age categories, the final grouping of those "6 years and older" up to 16 years of age. This category blurs potential analytical distinctions about children who experience huge developmental changes over this significant age range. However, Lipina et al. (2005) and others reflect progress in fuller appreciation of children in relation to executive function, previously understood to be adult-only capacity, overcoming inaccurate, discriminatory assumptions about children. Lipina et al. (2005) also pay attention to the role of culture in their research, noting that children's skills, cognitive strategies, and brain organization may be influenced. These findings reflect the positive demands of non-discrimination principle in research practice and should be emulated. Spera (2005, p. 141) acknowledges context in parenting and that more investigations are needed about the "larger cultural and economic context in which families reside." Such recognition of the complexities affecting children also reflects non-discrimination and is a valuable research direction.

Others also recognize discrimination's potential influence upon research and results including:

- Noble et al. (2012) who identify their results are not explained by gender, race, or IQ. Gender dimensions for instance, concern both girls and boys in terms of brain development and other influences (Younger et al., 2005).
- Johnson et al. (2007) who investigate the relationship between SES and school grades in biological and adoptive families.

While these studies are positive contributions, researchers can generally improve elaboration of, and respect of the non-discrimination principle.

The negative history of academic psychology, as Raizada and Kishiyama (2010), pp. 1–2, 8 describe, has involved researchers attempting to attribute learning difficulties "to genetic inferiority" and the stereotyping of people in poverty as "somehow inferior or undeserving." However, material wealth does not always determine success since research found the 25% of Canadian children who are not school-ready includes middle-class [Canadian Coalition for the Rights of Children (CCRC), 2011, p. 52]. Further, if children are less successful on such scientists' measures as IQ, and subject to labeling as "low SES" or having "deficits," what are the implications for children and their development? Moreover, as attention to SES has sprung from some children's adverse development paths, then the negative starting point will inevitably affect the research questions, process, and results. It is important that more positive children's characteristics including resilience are identified (Hackman and Farah, 2009) and explored in research.

Power is a relevant issue in research as Esterberg outlines:

> "…researchers need to address the power relationships… Researchers…often tend to be of a higher social class than the research participants…determine how the research is conducted…set the agenda and determine what is important… Research participants…do not typically have the power to determine, ultimately, how the data are used" (qtd. in Grover, 2004, p. 89).

Twelve-year-olds Maxine, John, and Stones confirmed: "Adults have power over children. Children aren't as respected" (Collins, unpublished). This power dynamic can result in discriminatory research. Thus, a CRBA to researching SES demands not only representation of different populations as study subjects, but also greater attention to how discrimination may affect children and research. The development of appropriate, standard categorizations would advance research to reflect greater diversity of children and respect non-discrimination.

BEST INTERESTS

The best interests of the child shall be "a primary consideration" in all actions concerning children according to CRC a.3, requiring a child focus. Neuroscience can improve its respect of this challenging principle since children are not always the explicit concern. For example, one paper identifies interest in neural data and behavior yet neglects to identify "child" in the paper's title or abstract (Raizada and Kishiyama, 2010). But some research reflects this principle well including Lipina et al. (2005) who concluded that executive function is no longer understood as only an adult capacity. To be clear, assumptions that ignore or exclude either the uniqueness and/or capacities of the child are problematic to best interests.

This principle is relevant to some psychology definitions of children's success, which do not necessarily reflect CR. While school readiness (Han et al., 2012), grades (Johnson et al., 2007), and other such achievement concerns are societally pertinent, should we only define children by such priorities, rather than for instance children's efforts or processes pertinent to brain development? The Roeher Institute (2002) recognizes children's different developmental paths are not reflected in much research resulting with: children's exclusion or interpretation as failures due to inability to achieve the measured outcomes; and/or negation of children with disabilities. Thus, critical analysis of research tools and methods is required to determine whether they exclude, rather than assess, children in accordance with best interests and a CRBA (Collins, 2008).

MAXIMUM SURVIVAL AND DEVELOPMENT

The child's right to maximum survival and development (CRC a.6) requires support of health, developing capacities, and abilities. Research should thus measure improvement or worsening of health and development over time (Collins, 2007). Accordingly, valuable findings from neuroimaging illustrate the impact on the developing brain of neglect and other stressors (Guyda et al., 2006) and support warm parental care during early childhood for brain maturation (Rao et al., 2010). Gianaros and Manuck (2010) acknowledge potential changes to SES at the individual and community levels over time will benefit future research. This is positive since the environment encircling the child influences his/her development as Bronfenbrenner, (1998) ecological model details.

The research value of longitudinal data is reinforced in assessing changes in children's development. But other research about specific development periods, including Blair et al.'s (2005) study of cortisol reactivity and executive function in 4- to 5-year-olds, is valuable to further knowledge. Furthermore, various data sources and approaches can complement efforts including "microlevel approaches, growth-curve modeling (e.g., van den Boom and Hoeksma, 1995), or qualitative data, to their correlational approach" (Paulussen-Hoogeboom et al., 2007, p.450) to advance the survival and development principle.

CHILD PARTICIPATION

In all matters concerning him/her, CRC a.12 affirms the child's right to express his/her own views freely to be given "due weight," but this principle remains a research challenge (Collins, 2007). While the research priority of mothers' parenting role inspired a correct call for more attention to fathers (Paulussen-Hoogeboom et al., 2007), a CRBA demands meaningful child participation in studies about children. Children's own knowledge and ideas about issue(s) under consideration tend not to be studied (Grover, 2004), and yet offer an exciting new direction for psychological research. Children's contributions will inform understandings of, and approaches to children by others. While most children may not be aware of specific hormones or brain regions for instance, they can support research in many ways including identifying: research areas in neuroimaging and SES; and new emerging issues in SES. While not referring to child participation, Gianaros and Manuck (2010) have identified progress in neurobiological understanding of SES requires improvements in measurement and interpretation of SES indicators. They explain subjective SES measures "other than income, education, and occupation" could be used (Gianaros and Manuck, 2010, pp. 458–459). This future direction would benefit from children's contributions and advance research and understandings about children.

CONCLUSION

In short, how do we approach and understand children? Science is not about what we know since it "is defined in terms of how and why we know something" (McCain and Segal, 1973, p. 36). CR are important in scientific inquiry in challenging assumptions, methods, tools, and results about children. A CRBA will complicate research efforts of SES impact upon children but will also improve research and understanding about children.

Brief recommendations to researchers to support a CRBA include:

i Improve CR understanding;
ii Assess role and impact of CR upon research; and
iii Incorporate a CRBA in research.

Researchers concerned about children should improve their CR knowledge and utilization since Eekelaar (1992, p. 234) explains:

> "It would be a grievous mistake to see the Convention [CRC] applying to childhood alone.… The Convention is for all people. It could influence their entire lives."

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Air pollution, socioeconomic status, and children's cognition in megacities: the Mexico City scenario

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INTRODUCTION

Megacities around the world have significant problems with air pollution (Molina and Molina, 2004; Chen and Kan, 2008; Parrish and Zhu, 2009). Metropolitan Mexico City (MC) – an example of extreme urban growth and serious environmental pollution with 20 million people, over 40,000 industries and four million vehicles – exhibits marked regional differences in air pollutants concentrations including industrial and mobile sources of contaminants (Ezcurra and Mazari-Hiriart, 1996; Moreno et al., 2008; Querol et al., 2008; Salcedo et al., 2010). Eight million MC children experienced serious detrimental effects including neuroinflammation, neurodegeneration, and cognition deficits (Calderón-Garcidueñas et al., 2008a,b,c, 2011a,b, 2012). Neighborhoods' proximity to main roadways, unpaved roads, dumps, and factories affect children's health and 27% of the MC population mostly to the north and east falls in this category (**Figure 1**).

While both children living in North Mexico City (NMC) and those in South Mexico City (SMC) are exposed to air pollution, the specific pollutant agents are quite different. NMC children are exposed to high concentrations of fine particulate matter ($PM_{2.5}$), and its constituents: organic and elemental carbon, secondary inorganic aerosols (SO_4^-, NO_3^-, NH_4^+), and metals (Zn, Cu, Pb, Ti, Mn, Sn, V, Ba), while SMC children are exposed to high ozone concentrations and PM-associated with lipopolysaccharides. This is important because exposure to specific pollutants may lead to specific detrimental effects (Rivas-Arancibia et al., 2010; Villarreal-Calderon et al., 2010; Levesque et al., 2011).

The neuropathology in MC mongrel dogs have shown DNA oxidative damage, Alzheimer's-type pathology, and accumulation of combustion-associated metals in olfactory mucosa, olfactory bulb, and frontal cortex, suggesting Alzheimer-like pathology and the resulting systemic and brain inflammation could be the consequence of air pollutant exposures (Calderón-Garcidueñas et al., 2002, 2003). In humans, the extensive respiratory inflammation targets the nasal epithelium first (Calderón-Garcidueñas et al., 1992). The pulmonary damage is equally severe and boys are more affected than girls, an observation likely related to their longer outdoor exposure hours (Calderón-Garcidueñas et al., 2003). Systemic inflammation, endothelial dysfunction, and high concentrations of interleukin-1β and tumor necrosis factor-alpha (TNF-α) with major impact in the brain (endothelial cells have receptors for these inflammatory mediators) are the norm in exposed

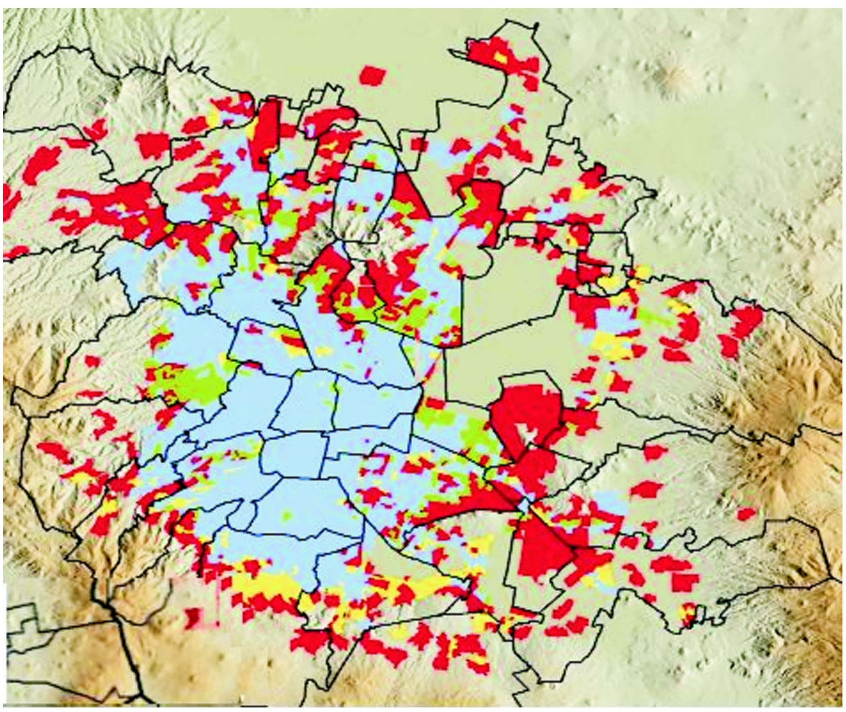

FIGURE 1 | Location of vulnerable population and housing groups in MC. Blue: not vulnerable; Green: vulnerable population; Yellow: vulnerable housing; Red: vulnerable population and housing. Population vulnerable areas have high concentration of people >18 years without secondary education and low SES. Housing vulnerable groups live in areas of poor construction housing, without access to basic services, and limited property ownership/rights. The black line shows the limits of the Federal District. (Figure reproduced with permission from The World Bank, 2011).

children. These children exhibit high concentrations of endothelin-1, a potent vasoconstrictor that impacts the brain microvasculature (Calderón-Garcidueñas et al., 2008a). Therefore, it came as no surprise to see the pathological, structural, and cognitive effects of the MC exposures in otherwise clinically healthy children (Calderón-Garcidueñas et al., 2011a). SMC children carefully selected for unremarkable clinical histories and no known risk factors for neurological or cognitive disorders compared to clean-air-controls matched for age, gender, and socioeconomic status (SES), exhibited significant deficits in a combination of fluid and crystallized cognition tasks (Calderón-Garcidueñas et al., 2008b), and 56% of MC children exhibited prefrontal white matter hyperintensities (WMH) similar to those in young dogs (57%). Even more striking, their cognitive deficits matched their MRI volumetric changes in their right parietal and bilateral temporal areas. Thus, exposure to air pollution may perturb the trajectory of cerebral development and result in cognitive deficits during childhood (Calderón-Garcidueñas et al., 2011a).

The MC children's neuropathology explain some of the clinical, electrophysiological, and brain MRI findings in our cohorts. The delayed brainstem auditory evoked potentials for example, correlate with the accumulation of α-synuclein and/or beta amyloid in auditory and vestibular nuclei (Kulesza and Muguray, 2008; Calderón-Garcidueñas et al., 2011b). In an autopsy cohort of 43 children and young adults (35 MC and 8 CTL), 40% exhibited frontal tau hyperphosphorylation with pre-tangle material and 51% had amyloid diffuse plaques compared with 0% in controls (Calderón-Garcidueñas et al., 2012). Hyperphosphorylated tau and amyloid plaques are seen in Alzheimer's disease and the development of neurodegenerative diseases must be contemplated as a potential long-term effect in exposed children.

It is clear that MC children, regardless of SES, are not healthy and detrimental short-term brain effects and potentially serious long-term effects are expected. Thus, in addressing the early cognitive and brain structural detrimental effects, we ask: do MC children have the capacity to recover from the observed negative neurological effects?

Anderson et al. (2011) reviewed how both early plasticity and early vulnerability may reflect opposite extremes along a "recovery *continuum*" which, we argue, is pertinent to our children. The detrimental pollution effects likely start *in utero* and continue relentlessly as the child grows up. Children's brains are fully capable of plasticity and neural compensation, thus our MRI observations of increased white matter volume (Calderón-Garcidueñas et al., 2011a), in connection with a well defined vascular lesion associated with low blood flow (Foscarin et al., 2012), is not surprising. Neural compensation has been described in association with white matter lesions, infarcts, and in healthy subjects as a function of training and experience. Specifically, Duffau (2009) compensatory mechanisms following white matter damage included: unmasking of peri-lesional latent networks, recruitment of accessory pathways, introduction of additional relays within the circuit, and involvement of parallel long-distance association pathways. If the child's responses to a single insult depend on a complex set of factors (the nature of the insult, the severity, the timing, cognitive reserve, genetic makeup, nutrition status, family function, etc.), the responses of a child continuously exposed to a polluted environment may even be more complex. Her capacity to compensate and overcome the developmental disruption may be far more intricate given the neuroinflammation and the presence of pathological markers of neurodegeneration (Calderón-Garcidueñas et al., 2012).

WHY ARE LOW SES CHILDREN MORE VULNERABLE THAN MIDDLE OR HIGH SES CHILDREN IN MC?

Low SES children lack the support they need to develop what Diamond and Lee (2011) consider the four qualities required to be successful: creativity, flexibility, self-control, and discipline. Accordingly, low SES children in MC attend public schools that are well known for deficient curricular programs, lack of creativity, flexibility or disciplinary practices, and teachers' unprofessionalism and absenteeism (Loret de Mola and García Bernal, 2012). Deficient schools do not help in the development of executive function skills and do not build cognitive reserves. Low SES children in MC have emotional and social needs, which are also exacerbated by domestic, school, and street violence (Cicchetti et al., 2010; Liu, 2011). These children are facing a significant rise in crime and violence in their neighborhoods (Davis, 2009) in a country where 52 million people have incomes below the poverty line.

On the other hand, typically children from middle and high SES families have access to balanced nutrition and cognitively stimulating home and school environments. Have parents that can afford services and resources for their specific need, and attend schools with stimulating curricula, including teaching a second language. Middle or high SES children live in neighborhoods with lower crime rate and have access to private pediatric care. Thus, the factors accounting for chronic stress in low SES children are typically not present in the higher income cohorts. In keeping with Cicchetti et al. (2010, 2011), Rogosch et al. (2011), and Sturge-Apple et al. (2012) the significant impact of high environmental stress is likely affecting predominantly low SES MC children.

CONCLUSION

Do we all breathe the same air in MC? Not quite. Low SES children are more likely to be live in environmental unjust communities, are exposed to second and third hand tobacco smog, and are more likely smokers themselves. They have higher chances of residing in high-density multiunit dwellings, with proximity to high traffic streets and factories, gas stations, mechanical shops, or share their living spaces with a home polluting business.

Environmental justice/inequity studies suggest the level of pollution present in the environment in which vulnerable populations reside is higher than in more affluent areas (Jerrett et al., 2001; Morello-Frosch et al., 2002; Prochaska et al., 2012). Subjects in poor areas are more likely to spend time close to or in traffic, working on the street, walking long distances to find transport and commuting in congested, dangerous transport. Thus, there is an urgent need to investigate the role of air pollutants in the different MC neighborhoods and their association with children's cognitive and behavior responses.

Epidemiological studies should be carried out to precisely determine the spatial distribution of air pollution health risks, followed by environmental protection measures and public health interventions. Research addressing low SES children's physiological regulatory capacities and cognition and developmental outcomes should also be carried out. To address the low SES children's detrimental responses to their physical and social environments (Jerrett et al., 2001; Morello-Frosch et al., 2002; Cicchetti et al., 2010, 2011; Rogosch et al., 2011; Prochaska et al., 2012; Sturge-Apple et al., 2012), efforts should be aimed to:

1) modify the current public school curricula to build executive function skills and cognitive reserves, which require trained supportive teachers and good quality school infrastructure;
2) provide access to free school lunch with balanced healthy diets; and
3) facilitate access to free good pediatric care, including mental health services.

Furthermore, if early childhood air pollution exposures related to SES disadvantage can increase the neurodevelopmental and neurodegenerative risk in the exposed child, then the need for interventions aimed at breaking the cycle of childhood poverty, poor food security, high unemployment, air pollution, and the negative health consequences becomes heightened.

We envisioned the protection of children to include cognitive interventions (Diamond and Lee, 2011), but it is important to remember that these approaches work if the children's emotional and social needs are also fulfilled. All efforts – nutritional, academic, extracurricular – are necessary, but insufficient if indeed the air children breath is not clean, and the environment is violent and stressful.

We need environmental justice for Mexico City exposed children. As Cureton (2011) stated, "*environmental injustice recognizes that economically disadvantaged groups are adversely affected by environmental hazards more than other groups*." Low SES MC children urgently need a support system involving parents, teachers, the health system, and government initiatives to improve environmental health. Besides addressing short-term brain outcomes, we need to investigate the long effects of neuroinflammation and if we are facing an Alzheimer's/Parkinson's epidemic in 30 years. Comprehensive epidemiologic investigations of air pollutant components exposure in pediatric populations and social health outcomes, including measures of delinquent or criminal activity are also needed (Haynes et al., 2011). Childhood aggression and teen delinquency are increasing in Mexico City, establishing an early environmental health risk factor for violence prediction, and prevention (Liu, 2011) in populations at risk will be absolutely critical.

Unfortunately while we wait for governmental sectors to address these endemic issues, there are no coverings for our children's noses, nor for their lungs, hearts or vulnerable brains. The body of knowledge gleaned from rigorous air pollution studies should be taken seriously by those concerned with health policy and public health. The unfortunate combination of poverty and air pollution are causing serious adverse, and often irreversible, health outcomes in our children.

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The rights and freedoms gradient of health: evidence from a cross-national study

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This study examined the combined influences of national levels of socioeconomic status (SES), social capital, and rights and freedoms on population level physical and mental health outcomes. Indicators of mental health were suicide rates, alcohol consumption, and tobacco use. Indicators of physical health included life expectancy, infant mortality rates, and prevalence of HIV. Using pathway analysis on international data from a selected sample of European, North American, South American, and South Caucasus countries, similar models for mental health and physical health were developed. In the first model, the positive effects of SES and social capital on physical health were completely mediated via rights and freedoms. In the second model, the positive effect of SES on mental health was completely mediated, while the impact of social capital was partially mediated through rights and freedoms. We named the models, the "rights and freedoms gradient of health" in recognition of this latter construct's crucial role in determining both physical and mental health.

Keywords: physical health, mental health, health, rights, freedoms, gradient, social capital, socioeconomic status

INTRODUCTION

Understanding how social and political forces determine population health outcomes across the life cycle is an overwhelming task. The diversity in the social and political systems that make up today's global community makes this task even more daunting. However, despite this diversity, there is one pattern that has emerged in virtually all societies, and for a wide range of outcomes: the social gradient of health (Marmot et al., 1991; Deaton, 2002; Kosteniuk and Dickinson, 2003; Wilkinson and Picket, 2009). In the context of national trends, the gradient refers to an individual's position in a socioeconomic hierarchy: individuals with less income are at greater risk for poorer health than individuals with greater income (Mathews and Gallo, 2011). By virtue of being a gradient, this principle applies to all income levels with not only the poorest being at greater risk of ill-health than the richest, but also with the well-off being at risk of poorer health than the richest. In the context of international trends, the gradient demonstrates that poorer countries have worse health outcomes than wealthier counties (Dasgupta and Weale, 1992).

Given the large body of evidence, this notion of a "social gradient of health" has become an accepted tenet in the field of social determinants. However, much debate ensues as to how the social gradient determines health outcomes (Wilkinson, 2000).

Considerable interest has been generated by the "*social inequality argument*" that draws attention to the steepness of the gradient line: the greater the income inequality, the steeper the social gradient of health. As such, the social inequality argument maintains that the wealthiest nations do not necessarily have the best health, but rather, that nations with the most egalitarian distribution of wealth have the best health outcomes (Marmot, 2002; Wilkinson and Picket, 2009).

In the context of child development, research suggests that early childhood is a particularly sensitive time for the determination of life-long health outcomes. Specifically, the prenatal, perinatal periods, and the early years have been shown to be the most sensitive to the effects of social inequality (Barker, 1997; Jefferis et al., 2002). Therefore, the available evidence pertaining to the social inequality argument reinforces the idea that economic factors, such as socioeconomic status (SES) and income distribution, account for a country's life-long health outcomes.

In parallel, the "*civil society and social capital argument*" has also gained recognition in the field of health and its social determinants. This argument postulates that individuals are healthier where people collectively organize themselves in informal, non-governmental, and/or voluntary associations. According to the World Health Organization (WHO) Civil Society Initiative, "civil society is usually understood as the social arena that exists between the state and the individual or household. Civil society lacks the coercive or regulatory power of the state and the economic power of the market but provides the social power or influence of ordinary people" [World Health Organization (WHO), 2001, p. 3]. A closely related and much overlapping construct is that of social capital. Social capital is a multi-dimensional construct that has been described as the interaction between individuals in social associations or networks that generates cooperation and trust required for the realization of common goals (Putnam, 2000). Mounting empirical evidence has suggested that social capital is linked to better individual health outcomes at the community, regional, and other sub-national levels (Islam et al., 2006). For example, Maggi et al. (2011) found that preschool children had better mental health outcomes in communities where coalitions of early childhood educators were a stronger presence in the local community. However, cross-national research examining social capital and country-level health outcomes has either been relatively scarce or not necessarily shown positive results, especially in the context of developed countries (Kennelly et al., 2003). Yet, comparisons of developed and developing countries have shown a positive influence of social capital on physical health outcomes (Elgar, 2010).

Finally, supported by decades of cross-national research (Dasgupta, 1990; Frey and Al-Roumi, 1999; Franco et al., 2004; Altman and Castiglioni, 2009) the "*rights and liberties argument*" proposes that political rights and civil liberties are responsible for improvements in life expectancy and child survival. Political rights and civil liberties define democracy and freedom as the degree to which "the power of the elite is minimized and that of the non-elite is maximized" (Bollen, 1980, p. 372). Accordingly, political rights and civil liberties are organizational arrangements that reflect the extent to which power is distributed to non-elites (Bollen, 1986). Political rights allow citizens to choose who governs their nation and what laws and policies shall exist. Civil liberties include freedom of expression, association, speech, and media that are protected by the rule of law. As such, these liberties protect individuals' expression of opinions without fear of reprisal from the state (Dasgupta, 1990). A population with greater civil liberties possesses a greater capacity to influence the decisions of the elite (Gearty, 2003). Directly connected to the rights and liberties argument is the ability of democracies to curb corruption (Drury et al., 2006), an important factor associated with infant and child mortality rates (Gupta et al., 2000).

The three arguments of social inequality, civil society and social capital, and rights and liberties lend themselves to being integrated into one complementary view. It has been reasonably argued that in addition to influencing health outcomes directly, improvements in wealth distribution lead to gains in civil society and social capital, which in turn improve health outcomes of individuals and whole countries. This school of thought is evident in the social determinants of health framework put forward by the WHO Commission on the Social Determinants of Health, after much consideration of the extant interdisciplinary literature on the topic [World Health Organization (WHO), 2010]. As shown in **Figure 1**, socioeconomic and political factors are conceptualized as structural determinants, while the intermediary determinants are viewed as proximal influences (e.g., living and working conditions) and biological predispositions. Social cohesion and social capital are noted to act as influences between these structural and intermediary determinants.

In this model, the social inequality and rights and liberties arguments, although not explicitly embedded in its graphic representation, would be placed with the socioeconomic and political structural determinants. The civil society and social capital argument has been placed between the structural and intermediary determinants, acting somewhat as a mediator between the two. This framework, while acknowledging the bi-directionality of many of its influences, proposes a pathway leading to better health

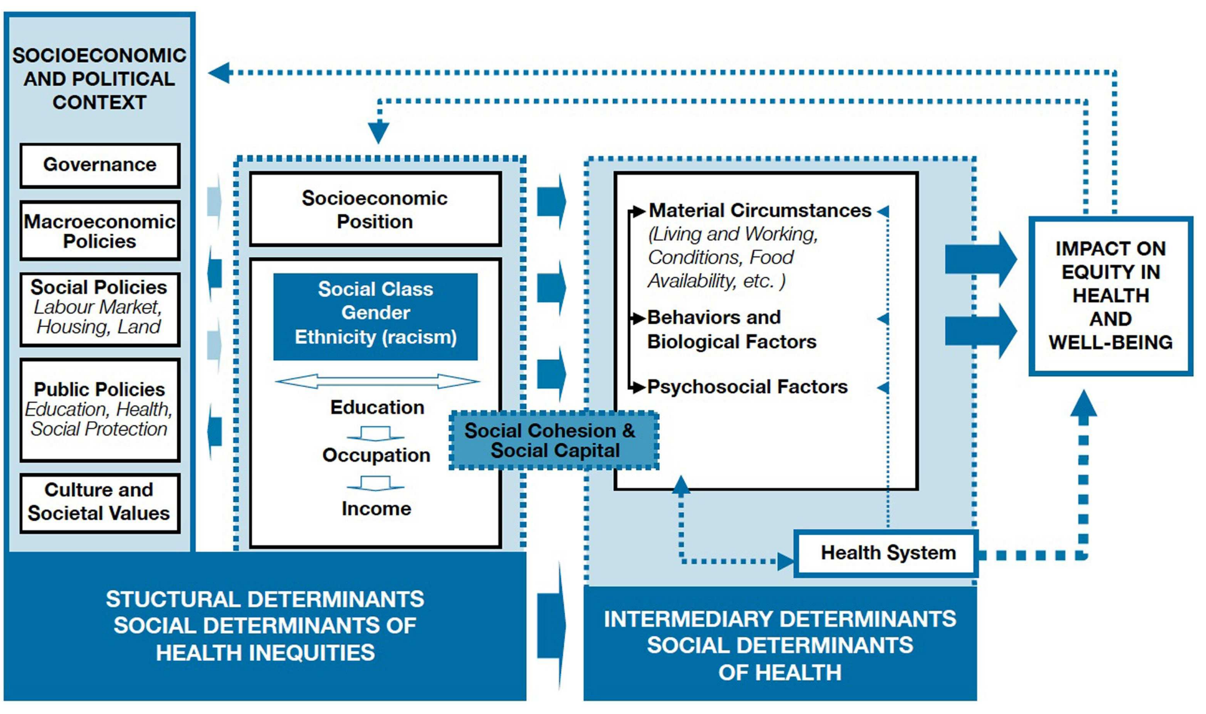

FIGURE 1 | WHO framework of social determinants of health [World Health Organization (WHO), 2010]. Permission was granted to reproduce this diagram as it was originally published by the World Health Organization (WHO; 2010) on page 6 in A Conceptual Framework for Action on the Social Determinants of Health.

that commences from good governance and national wealth, leading to improvements in the social and socioeconomic conditions of individuals, who in turn are able to contribute to improvements in civil society and social capital. This WHO framework of the social determinants of health offers a logical and well-researched integration of the three explanatory arguments discussed above (i.e., social inequality, civil society and social capital, and rights and liberties) that may help to explain the determining forces behind the social gradient of health.

In this study, we applied the WHO framework to international data pertaining to 34 European, North and South American, and South Caucasus countries. We gathered indicators of physical and mental health outcomes pertaining to children (i.e., infant mortality), and youth and adults (i.e., suicide, tobacco and alcohol use, HIV/AIDS, and life expectancy). Our expectation was that, consistent with the WHO framework, good governance (rights and liberties) would promote gains in wealth and reductions in social inequality, which in turn would be associated with better health outcomes. We also expected civil society and social capital to moderate the effect of SES. In other words, we expected that wealthier countries with high social capital would have better health outcomes than better-off countries with low social capital.

MATERIALS AND METHODS

MEASURES AND SAMPLE

Data were obtained from online databases and publications of the WHO, World Bank, United Nations (UN), Freedom House, Transparency International, International Labour Organization (ILO), and the World Values Survey (WVS). Our full sample consisted of 34 countries from Europe, North and South America, and the South Caucasus that included (in alphabetical order): Albania, Argentina, Armenia, Brazil, Canada, Chile, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Mexico, Moldova, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovenia, Spain, Sweden, Ukraine, United Kingdom, and United States of America (USA). As the WVS (that was used to study the role of social capital) did not have data for all of the nations in the full sample, we also conducted analysis on a subsample of 23 countries for which data on social capital was available. The 23 countries from Europe, North and South America, and the South Caucasus included (in alphabetical order): Argentina, Brazil, Canada, Chile, Finland, France, Georgia, Germany, Italy, Mexico, Moldova, Netherlands, Norway, Poland, Romania, Russia, Serbia, Slovenia, Spain, Sweden, Ukraine, United Kingdom, and United States of America.

SOCIOECONOMIC STATUS

Gross domestic product (GDP) per capita (US$), the Gini index, and unemployment were used to measure national levels of SES. GDP is defined as the total output of goods and services by a national economy. GDP per capita data, from 2008, were obtained from the World Bank Indicators Online (World Bank, 2012a) and are defined as the GDP divided by the national population.

Data for the Gini index were obtained from the World Bank's World Development Indicators publication and were used to measure income inequality. A value of zero represents perfect income equality, whereas 100 represents absolute inequality (World Bank, 2011). The Gini data ranged from 1996 to 2009. However, only available data for the single, most recent year of any given nation were used. Approximately, 82.35% of Gini data were from the year 2000 or more recent.

Unemployment is considered one of the broadest economic indicators as reflected by the labor market (World Bank, 2011) with data obtained from the ILO's Key Indicators of the Labor Market database [International Labour Organization (ILO), 2011]. Specifically, unemployment data represent the percent of the total labor force that is devoid of, but is available for and searching for, work. Data ranged between the years 2006 and 2010. Only unemployment data for the single, most recent year of any given nation were used.

SOCIAL CAPITAL

Social capital indicators for membership in associations, trust, and political activism were obtained from the 2005–2008 wave of WVS (World Values Survey Association, 2008). The Survey's association sources local teams to collect data in their respective countries, thereby monitoring international trends in values and beliefs. Every nation was surveyed once during the 2005–2008 wave. Our subsample of 23 nations with WVS data included 28,856 participants.

Measures assessing trust in institutions, that included the police, courts, government, the press, and political parties, were originally rated on four-point scales, with 1 and 2 indicating trust ("completely trust" or "trust somewhat") and 3 and 4 indicating lack of trust ("do not trust very much" or "do not trust at all"). These scores were dichotomized so that 1 indicates complete or partial trust and 0 indicates complete or partial distrust. Thus, mean values for these variables are the proportion in the sample trusting a particular institution (press, police, courts, government, political parties). Political activity was assessed by self-reports of signing a petition, attending a demonstration, or participating in a boycott. Results were scored as 1 (="have done") or 0 (="might do" or "would never do"). Respondents were asked if they were active or inactive members of nine different types of organizations. We grouped active and inactive responses together (=1), in contrast to those who indicated that they had never belonged to that type of organization (=0). We considered three different types of membership: churches or religious organizations; labor unions; and, all other organizations that included sports, arts or music, political parties, environmental, professional, charitable, or consumer organizations.

RIGHTS AND FREEDOMS

Measures of political rights, civil liberties, and corruption were used to evaluate rights and freedoms in the sample of nations. Indicators of democracy from the year 2008 were obtained from Freedom House based on their political rights and civil liberties indices (Freedom House, 2011a). The political rights index assesses the electoral process and free and fair elections, political pluralism, freedom to participate in the political process, and functioning and transparency of government. The civil liberties index assesses freedom of expression, belief, association, and organization. This latter index also assesses the rule of law, personal autonomy, and individual rights (Freedom House, 2011b). Both indices are rated on a 1–7 scale, with 1 being the highest and 7 being the lowest. However, for sake of interpretation, the original political rights and civil liberties scores were reflected where 1 represented low and 7 denoted high levels of political and civil liberties.

Measures of perceived corruption related to the public sector (Transparency International, 2012a) were obtained from Transparency International. The 2008 country scores were originally measured on a ten-point scale, where zero (0) denoted high and 10 indicated low levels of corruption (Transparency International, 2012b).

PHYSICAL HEALTH

Measures of physical health included life expectancy, infant mortality rates, and prevalence of HIV in youth and adults. Life expectancies were obtained from the World Population Prospects database of the UN for the combined years of 2005–2010. Life expectancy at birth in years was calculated by the UN as "the average number of years of life expected by a hypothetical cohort of individuals who would be subject during all their lives to the mortality rates of a given period" [United Nations (UN), 2011]. Infant mortality rates, collected for the year 2010 from the World Bank's online data base, are the number of infants dying prior to reaching 1 year of age per 1000 live births (World Bank, 2012b). HIV data were obtained from the UNAIDS Report on the Global AIDS Epidemic [United Nations (UN), 2010] and were defined as the estimated percentage of 15–49 year olds in the population living with HIV in 2009.

MENTAL HEALTH

Mental health was assessed with measures of suicide rates, tobacco use, and alcohol consumption. International suicide rates per 100,000 were obtained from the WHO's online mental health country charts [World Health Organization (WHO), 2012]. Suicide data ranged from 2003 to 2009. Only available data for the single, most recent year of any given country were used. Of the 34 nations, 82.35% of the suicide data were from the years 2007–2009.

Data for the percentage of national populations that engaged in current-daily tobacco-cigarette smoking were obtained from appendix 8 of the WHO's Report on the Global Tobacco Epidemic [World Health Organization (WHO), 2011a]. This data did not represent youth tobacco use rates, although: 1 country reported for ages 11 and up; 1 country for ages 12 and up; 19 countries reported for ages 15 and higher; and, 4 countries reported tobacco use concerning individuals ages 16 and up. Tobacco data, for any given nation, were obtained for the single, most recent available year between 2000 and 2010; 76.47% of this data were from the years 2007–2010. Data for alcohol consumption was retrieved from the WHO's Global Health Observatory Data Repository [World Health Organization (WHO), 2011b]. These 2005 data indicate the total recorded and unrecorded consumption per capita, in liters of pure alcohol, for ages 15 years and up.

PROCEDURE

For our path models, the latent variable partial least squares (LVPLS) approach developed by Lohmöller (1984) was used. According to Falk and Miller (1992) and Wold (1980), LVPLS is particularly appropriate when relations between theoretical constructs cannot be specified exactly, when empirical measures have some degree of unreliability, when there are many manifest and latent variables, and when sample sizes are moderate or small. Thus, this type of analysis is particularly appropriate given the conditions found in the present study.

Lohmöller's (1984) approach does not generate standard errors for path coefficients (and hence tests of significance), on the grounds that this entails assumptions about the multivariate distributions that are difficult to test and unlikely to be true (Wold, 1980; Falk and Miller, 1992). Thus, we required that path coefficients and factor loadings be of at least moderate size. For example, Falk and Miller (1992) recommend factor loadings of at least 0.55, indicating that the manifest variable shares 30% of its variance with its latent variable. This criterion was met in our models with only two exceptions, as is revisited in the results. For path coefficients, we set a minimum size of 0.30. In contrast to path coefficients and factor loadings, we could and did apply tests of significance to the R^2 values generated by our models. All were significant, $ps < 0.001$.

Because path analysis requires complete data, missing values were estimated within domains if only one measure was missing. For example, if a country was missing one of three measures of mental health (such as tobacco use), that missing value was estimated by maximum likelihood procedures (BMDP AM, Dixon, 1992) using the other two mental health measures (alcohol consumption and suicide rate). Although this strategy slightly inflates coherence within domains, it does not affect relations between domains. For mental health, two countries were missing data for tobacco use and two others for alcohol consumption. For physical health, two countries were missing data for HIV infection rates. All countries had complete data for SES, and rights and freedoms. For the subsample, all 23 countries had complete social capital data.

RESULTS

This section begins with descriptions of the sample countries in terms of our variables of interest – SES, social capital, rights and freedoms, and physical and mental health. Next, the relations within and between these domains are examined, first by considering correlations between each of the individual measures, and second by aggregating these measures on latent variables using path analysis. Separate path models were developed for physical and mental health; and for each health outcome, relations were examined in the full sample of 34 countries and the subsample of 23 countries for which social capital data were available. For each of these four models, we examined the issue of whether, as we expected, SES directly predicted health outcomes, mediating relations between health and rights and freedoms (and social capital, when it could be examined). As seen below, although relations between SES and health were substantial, relations between rights and freedom and health were even stronger, and our analyses indicated that rights and freedoms mediated the effects of SES rather than vice versa. Similarly, in our subsample of 23 countries, we examined the issue of whether social capital directly predicted health, or whether the effects of social capital were mediated by rights and freedoms. As seen below, the answer to this question differed according to the health outcomes we considered, physical or mental.

DESCRIPTIVE FINDINGS

Socioeconomic status

As shown in **Table 1**, for these 34 nations, the mean GDP per capita was USD 26,048.01 (SD = 21,688.87). For the subsample of 23 nations, the mean was USD 28,814.15 (SD = 23,760.92). For both the full and subsamples, GDP per capita ranged from USD 1,696.0 (Moldova) to USD 95,189.9 (Norway). For the full sample, the mean Gini index was 34.13 (SD = 7.22); for the reduced sample, the mean was 34.68 (SD = 8.25). For both samples, Brazil had the highest Gini index of 53.9, while Chile had the lowest of 22.6.

Social capital

As shown in **Table 1**, police were the most trusted social institution (over half of WVS respondents), followed by the courts. Nearly half of respondents reported engaging in at least one political activity (signing a petition, attending a demonstration, or engaging in a boycott). Most people (60%) belonged or had belonged to organizations, but over a third of these (22.5% of the sample) reported that they were actively involved with only one group. Fewer than 10% of the sample were active in two groups, and fewer than 8% were actively involved with three or more groups. Considering active and inactive memberships together, over a third of the sample reported membership in religious organizations and nearly a fifth in labor unions (see **Table 1**). In the category of "other organizations," membership was most common in sports groups (24.8%), art/music/education groups (16.8%), and charities (16.5%), followed by professional organizations (12.8%) and political parties (11.1%).

Rights and freedoms

Of the 34 nation full sample, the average political rights score was 6.2 (SD = 1.4), while the average civil liberties score was 6.3 (SD = 1.1). In the full sample, several countries including Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Lithuania, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, United Kingdom, and USA were ranked as 7 for the highest level for both political rights and civil liberties. Russia was ranked the lowest for both political rights (2) and civil liberties (3). Of the 23 nation subsample, the average political rights score was 6.2 (SD = 1.3); the average civil liberties score was 6.2 (SD = 1.2). Of the subsample, Canada, Chile, Finland, France, Germany, Netherlands, Norway, Poland, Slovenia, Spain, Sweden, United Kingdom, and USA were tied for the highest level (7) for both political rights and civil liberties. In the reduced sample, Russia was ranked the lowest for political rights and civil liberties with scores of 2 and 3, respectively.

The average corruption score was 5.56 (SD = 2.18) for the 34 nation full sample. Specifically, Denmark and Sweden were tied for the lowest level of perceived corruption with a score of 9.3. Russia had the highest perceived level of corruption with a score of 2.1. Of the 23 nation subsample, the average corruption score was 5.73 (SD = 2.39). Of the subsample, Sweden was rated as the least corrupt with a score of 9.3, while Russia was rated as the most corrupt with a score of 2.1.

Physical health

The average life expectancies were 76.25 (SD = 3.98) and 76.60 (SD = 4.47) years in the full and subsamples, respectively. Of both samples, Italy had the longest life expectancy with 81.37, while Ukraine had the lowest with 67.54 years. The average infant mortality rates were 7.31 (SD = 5.27) and 7.58 (SD = 5.37) per 1000 births for the full and subsamples, respectively. Of both samples, Slovenia had the lowest infant mortality rate of 2.3 per 1000 births, while Georgia had the highest of 20.0. Of the 34 nation full sample, the average prevalence of HIV was 0.31% (SD = 0.31). Several countries, including Croatia, Czech Republic, Hungary,

Table 1 | Descriptive statistics *N*s = 34 and 23.

Variable	Mean	SD	Minimum	Maximum
***N* = 34**				
SES				
GDP (per capita, USD)	26,048.01	21,688.87	1,696.0	95,189.9
GINI	34.13	7.22	22.6	53.9
Rights and freedoms				
Corruption	5.56	2.18	2.1	9.3
Political rights	6.2	1.4	2	7
Civil liberties	6.3	1.1	3	7
Mental health				
Suicide (per 100,000)	13.39	7.71	1.9	34.1
Alcohol consumption	17.92	5.21	8.68	27.91
Tobacco (% daily use)	23.59	6.45	7.6	40.2
Physical health				
Life expectancy (years)	76.25	3.98	67.54	81.37
Infant mort (per 1,000)	7.31	5.27	2.3	20.0
HIV (% prevalence)	0.31	0.31	<0.1	1.2
***N* = 23**				
SES				
GDP (per capita, USD)	28,814.15	23,760.92	1,696.0	95,189.9
GINI	34.68	8.25	22.6	53.9
Social capital				
% Trust police	56.0	21.5	19.9	91.5
% Trust courts	46.1	18.6	19.5	86.0
% Politically active	44.7	21.5	9.3	80.4
% Church members	35.9	21.5	7.5	78.5
% Union members	19.9	14.1	3.2	58.5
% Members of other org.	45.0	21.4	2.7	83.5
Rights and freedoms				
Corruption	5.73	2.39	2.1	9.3
Political rights	6.2	1.3	2	7
Civil liberties	6.2	1.2	3	7
Mental health				
Suicide (per 100,000)	12.73	6.51	4.2	30.1
Alcohol consumption	17.26	5.49	8.68	27.91
Tobacco (% daily use)	22.18	6.31	7.6	33.8
Physical health				
Life expectancy (years)	76.60	4.47	67.54	81.37
Infant mort (per 1,000)	7.58	5.37	2.3	20.0
HIV (% prevalence)	0.32	0.28	<0.1	1.1

For the analyses, we substituted a point-estimate of 0.05 for the approximate value of <0.1 given in our sources. Lacking more precise information, this seemed a reasonable estimate because 0.05 is halfway between 0 and 0.1, and so unknown values <0.1 might be expected to center on it.

and Slovenia were tied for the lowest prevalence with less than 0.1% of the population living with HIV. The nation with the highest prevalence was Estonia with 1.2% of the population living with HIV. Of the 23 nation subsample, the average prevalence of HIV was 0.32% (SD = 0.28). In this latter sample, Slovenia had the lowest HIV prevalence (<0.1%), while Ukraine had the highest (1.1%).

Mental health

Of the 34 nations that comprised the full sample, the average suicide rate was 13.39 per 100,000 (SD = 7.71). Armenia had the lowest suicide rate with 1.9, while Lithuania had the highest occurrence with 34.1 per 100,000. The average suicide rate for the 23 nation subsample was 12.73 (SD = 6.51) per 100,000. Of the subsample, Mexico had the lowest suicide rate with 4.2, while Russia had the highest with 30.1 per 100,000. The average percent of tobacco-cigarette smokers in the full sample was 23.59% (SD = 6.45). Of the full sample, Mexico had the lowest (7.6%) percentage of tobacco users; Albania had the highest (40.2%). The average percent of tobacco-cigarette smokers in the subsample was 22.18% (SD = 6.31). Of the subsample, Russia had the highest percentage of adult tobacco users (33.8%), while Mexico had the lowest (7.6%). The average total alcohol recorded and unrecorded consumption per capita was 17.92 liters (SD = 5.21) and 17.26 liters (SD = 5.49) for the full and subsamples, respectively. For both samples, Ukraine had the highest level of consumption in liters (27.91); Norway had the lowest (8.68).

RELATIONS BETWEEN SES, SOCIAL CAPITAL, RIGHTS AND FREEDOMS, AND HEALTH: CORRELATIONS

Our measures of national level SES showed only moderate convergence. As shown in **Table 2**, greater GDP was significantly and moderately related to lower levels of economic inequality (Gini) and lower rates of unemployment, as expected. In contrast, unemployment and economic inequality were unrelated.

With the exception of church membership, our measures of social capital were all significantly and strongly related to one another and to GDP (all correlations >0.50; **Table 2**). In contrast, correlations between social capital and economic inequality and unemployment were less consistent and only moderately strong. Specifically, only five of ten comparisons were greater than 0.30, and all were less than 0.50.

The same pattern was shown by our three measures of rights and freedoms. Corruption, political rights, and civil liberties were strongly and significantly correlated with one another and with GDP, whereas correlations with economic inequality and unemployment were moderate and sometimes failed to reach statistical significance. Specifically, only four of six comparisons were greater than 0.30, and all were less than 0.50. Given their similar means and standard deviations (**Table 1**) and the very high correlation between civil liberties and political rights (see **Table 2**; in the subsample, $r = 0.94$), these two variables were averaged before entry into the path models.

As expected, many of the social capital variables were strongly and consistently related with our measures of rights and freedoms.

Our measures of mental health showed only weak convergence. Although suicide rates correlated about 0.30 with both alcohol consumption and tobacco use (and about 0.40 in the set of 23 countries for which we had social capital data), alcohol consumption and daily tobacco use showed little relation with one another in either the full or subsample. However, alcohol consumption and daily tobacco use were very similarly related to SES, rights and freedoms, and social capital. The median absolute correlations with these variables were 0.41 and 0.42, respectively, for alcohol and tobacco use. In contrast, suicide rate correlated with SES, rights and freedoms, and social capital at only chance levels.

A similar pattern within and across variables was seen for physical health. As expected, life expectancy showed good convergence with infant mortality and HIV rates. However, infant mortality and HIV were only weakly related to one another in the full and subsamples (**Table 2**; in the subsample, $r = 0.28$). And whereas life expectancy and infant mortality were both frequently and strongly related to SES, rights and freedoms, and social capital (8 of 12 correlations were greater than 0.50 for both variables), relations between these variables and HIV rates were at chance levels. Thus, within each set of three outcomes for physical and mental health, correlations indicated somewhat different patterns of association with our set of predictors.

RELATIONS BETWEEN SES, SOCIAL CAPITAL, RIGHTS AND FREEDOMS, AND HEALTH: PATH MODELS

Mediated and direct relations: SES and rights and freedoms

We began by considering models that were consistent with our theoretical expectations, namely, that SES was a direct predictor of health and mediated the effects of rights and freedoms. First in the subsample and then in the full sample, we asked whether SES or rights and freedoms had a stronger direct effect on health, and then whether any evidence existed for the direct effect of the weaker variable when the stronger variable was already a direct predictor. In these contrasting models (see **Figure 2**), social capital when present, always predicted rights and freedoms.

For the 23 countries for which we had data on social capital, rights and freedoms was a stronger predictor of health than SES, particularly for physical health. Consistent with its importance in other studies, SES predicted 64% of the variance in physical health in a path model in which it directly predicted physical health (Model I, **Figure 2**). But rights and freedoms proved to be even stronger, predicting 79% of the variance in physical health when it was the direct predictor (Model II, **Figure 2**). For mental health, SES directly predicted 41% of the variance (Model I) and rights and freedoms predicted 49% (Model II). Thus, these initial findings in the subsample were consistent with models in which rights and freedoms directly influenced both physical and mental health and in each case mediated the effects of SES.

We then examined a third model, one in which SES and rights and freedoms jointly predicted health. Specifically, in Model II, **Figure 2**, a direct path was added from SES to health. In this model, SES increased the explained variance in physical health by less than 2% in comparison to rights and freedoms alone, and path coefficients of 0.72 for rights and freedoms and 0.21 for SES indicated a minimal role for SES as a joint predictor. The joint model for mental health could not be interpreted because of suppressor effects for the SES-mental health path (as indicated by different signs for the path coefficient and the correlation between

Table 2 | Correlations between variables.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SES																	
GDP	1.00																
GINI	−0.40*	1.00															
Unemploy.	−0.41*	0.03	1.00														
SOCIAL CAPITAL																	
Trust police	0.85***	−0.45*	−0.09	1.00													
Trust courts	0.86***	−0.30	−0.21	0.87***	1.00												
Pol. active	0.79***	−0.12	−0.16	0.79***	0.78***	1.00											
Church	0.25	0.24	−0.33	0.31	0.51*	0.45*	1.00										
Union	0.61**	−0.42*	−0.37+	0.52*	0.75***	0.51*	0.50*	1.00									
Other org	0.75***	−0.19	−0.48*	0.64***	0.72***	0.84***	0.63**	0.67***	1.00								
RIGHTS AND FREEDOMS																	
Corruption	0.83***	−0.49**	−0.31+	0.85***	0.73***	0.72***	0.37+	0.54**	0.73***	1.00							
Pol. rights	0.55***	−0.25	−0.37*	0.64***	0.48*	0.59**	0.38+	0.25	0.59**	0.69***	1.00						
Civil lib.	0.54***	−0.41*	−0.20	0.62**	0.47*	0.57**	0.29	0.30	0.54**	0.72***	0.92***	1.00					
MENTAL HEALTH																	
Suicide	−0.10	−0.19	−0.01	−0.20	−0.09	−0.27	−0.29	0.21	−0.16	−0.06	−0.02	0.12	1.00				
Alcohol	−0.57***	0.29+	0.11	−0.66***	−0.46*	−0.66***	−0.23	−0.34	−0.54**	−0.55***	−0.36*	−0.35*	0.31+	1.00			
Tobacco	−0.44**	−0.24	0.34*	−0.32	−0.48*	−0.58**	−0.78***	−0.40+	−0.68***	−0.44**	−0.41*	−0.32+	0.28	0.15	1.00		
PHYSICAL HEALTH																	
Life expect.	0.72***	−0.33+	−0.24	0.78***	0.58**	0.70***	0.26	0.28	0.64***	0.76***	0.68***	0.59***	−0.45**	−0.60***	−0.42*	1.00	
Infant mort.	−0.66***	0.52**	0.26	−0.67***	−0.57**	−0.54**	−0.01	−0.42*	−0.55**	−0.69***	−0.72***	−0.75***	−0.31+	0.21	0.21	−0.62***	1.00
% HIV	−0.22	0.28	0.05	−0.35+	−0.26	−0.25	−0.15	−0.20	−0.23	−0.22	−0.21	−0.13	0.25	0.40*	0.07	−0.43*	0.11

N = 23 for correlations with social capital; for all other variables, *N* = 34. +$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. All tests are two-tailed. The binomial probability of observing 86 or more significant correlations in a set of 153 with alpha = 0.05 is <0.0001. This table uses 2008 data for GDP and rights and freedoms. Corruption is reverse-scored so that high scores = low levels of corruption. Suicide rate = rate per 100,000. Alcohol = alcohol consumption. Tobacco = % prevalence of daily tobacco use. Life expect = life expectancy in years. Infant mort = infant mortality per 1,000 live births. % HIV = % prevalence in population.

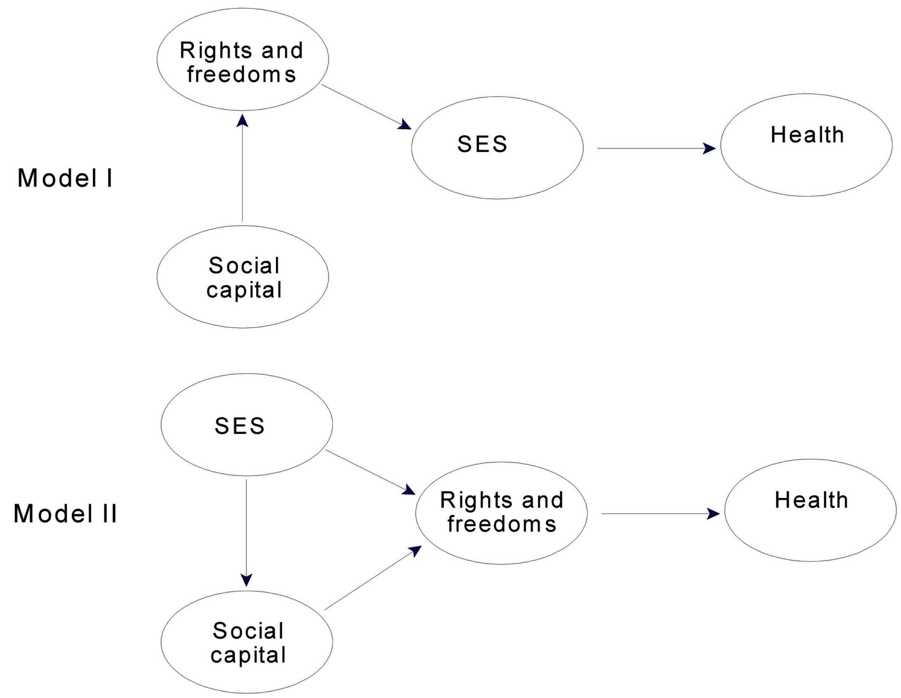

FIGURE 2 | Contrasting conceptual path models for evaluating direct and mediated effects for SES, and rights and freedoms for the 23 countries that had social capital data. Models for the full sample omitted the latent construct for social capital.

the latent variables). Thus, no joint predictor model indicated an important direct effect for SES once rights and freedoms was a direct predictor of health.

These analyses were then repeated using all 34 countries in our sample. The pattern just described for the subsample was found again: SES was a strong predictor of physical and mental health, but rights and freedoms was even stronger, particularly for physical health. For the model in which only SES directly predicted physical health (Model I, **Figure 2**, social capital omitted), SES accounted for just under 60% of the variance in physical health. In contrast, for the model in which only rights and freedoms directly predicted physical health (Model II, **Figure 2**, social capital omitted), rights and freedoms predicted 71% of the variance. For mental health, the respective values were 34% for SES in Model I and 39% for rights and freedoms in Model II. Therefore, findings in the full sample, like those in the subsample, indicated that rights and freedoms directly influenced health and mediated the effects of SES, rather than vice versa.

As the final step in assessing mediated and direct relations for SES and rights and freedoms, we examined in our full sample the model in which SES and rights and freedoms were joint predictors of health. In this model, SES increased the explained variance in physical health by 3.8% in comparison to rights and freedoms alone, and path coefficients of 0.59 for rights and freedoms and 0.32 for SES indicated a substantially stronger relation for rights and freedoms than for SES. In the joint model for mental health, SES increased explained variance by only 1% in comparison to rights and freedoms alone, and path coefficients of 0.51 for rights and freedoms and only 0.15 for SES indicated a very minimal role for SES. Thus, joint predictor models using the full sample were inconsistent in their implications. The model for mental health indicated no important direct effect for SES independent of rights and freedoms. In contrast, the model for physical health indicated a modest role for SES as a joint predictor, in that its path coefficient was greater than 0.30. But since this relation was not large and did not replicate in the subsample (the path coefficient for SES was only 0.21 in the joint model, as noted earlier), we concluded that the evidence for a joint role for SES in predicting physical health was insufficient.

In sum, although SES was strongly linked to physical and mental health outcomes in our sample, consistent with results from other samples, relations between rights and freedoms and health were even stronger and entirely (in the case of mental health) or almost entirely (in the case of physical health) mediated the effects of SES.

Mediated and direct relations: social capital and rights and freedoms

We approached the issue of direct and mediated relations for rights and freedoms and social capital using the same strategy as we did for SES and rights and freedoms, contrasting the path models shown in **Figure 3**. These contrasts, of course, could only be carried out in the subsample.

In the 23 countries for which we had social capital data, rights and freedoms clearly mediated relations between social capital and physical health. In Model I in **Figure 3**, rights and freedoms predicted 79% of the variance in physical health. The comparable value for social capital (Model II, **Figure 3**) was 61%. A third path

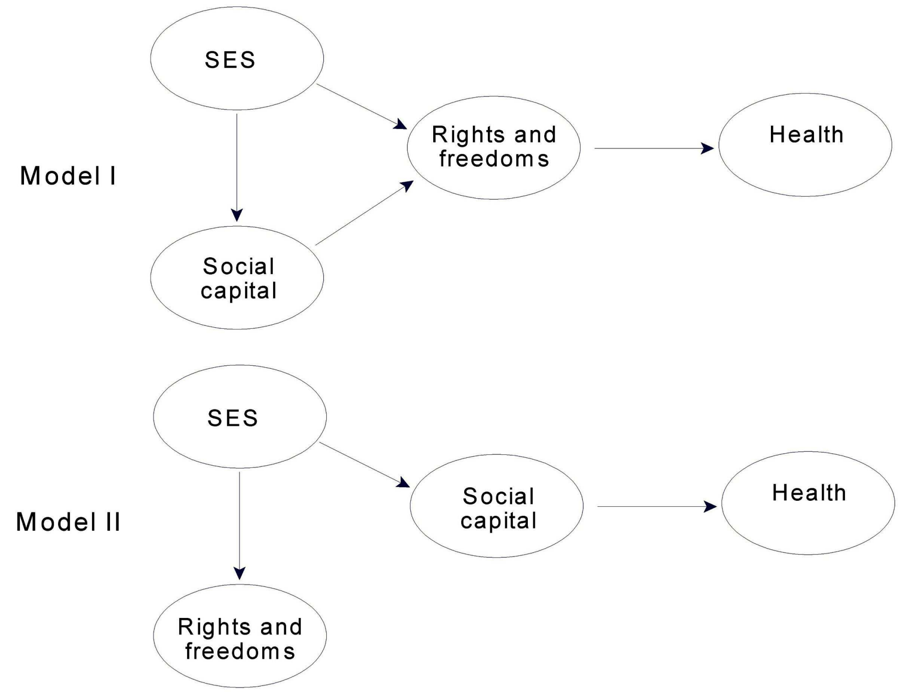

FIGURE 3 | Contrasting conceptual path models for evaluating direct and mediated effects for social capital, and rights and freedoms for the 23 countries with available social capital data.

model in which social capital was a direct, joint predictor of physical health (Model I with an added direct path from social capital to health) accounted for only 0.3% more variance in physical health than did rights and freedoms alone; and the small path coefficient for social capital (0.09) indicated that its role as a joint predictor was unimportant. Therefore, in the final model described below, the relation between social capital and physical health is mediated by rights and freedoms.

A different picture emerged when we considered relations between social capital, rights and freedoms, and mental health. When rights and freedoms directly predicted mental health (Model I, **Figure 3**), it accounted for 49% of the variance. When social capital directly predicted mental health (Model II, **Figure 3**), it was slightly stronger, accounting for 52% of the variance. A third path model in which rights and freedoms and social capital were joint predictors of mental health accounted for 54% of the variance. Although the increase over Model II was marginal (2%), the path coefficients were essentially equal (0.40 for social capital and 0.37 for rights and freedoms), indicating that both were important as joint predictors. Therefore, in the final model, described below, social capital and rights and freedoms both predict mental health. Because we had assessed mediation for SES using models in which the effects of social capital on mental health were mediated by rights and freedoms, we revisited this issue by assessing whether SES was an important direct predictor of mental health when social capital and rights and freedoms were joint predictors. The same pattern again emerged in this analysis: the direct path from SES to mental health had a suppressor effect, rendering the path model uninterpretable. Thus, there was no evidence to support a direct path between SES and mental health that was independent of rights and freedoms.

The final path models

This section describes the final models that emerged from our consideration of direct and mediated relations above, beginning with models for mental health. First, various aspects of fit between the models and the data are considered. Second, detailed descriptions of various aspects of the models, themselves, are presented.

Mental health was strongly predicted in the full sample (**Figure 4**), where rights and freedoms predicted over a third of the variance in a latent variable aggregating tobacco use and alcohol consumption and (to a lesser extent) suicide rate.

In the subsample, rights and freedoms together with social capital predicted over half the variance in mental health (**Figure 5**). In both models, well over half the variance in rights and freedoms was predicted by SES or by SES together with social capital.

In addition to strong relations between latent variables, the final models for mental health adequately summarized our manifest variables. Mean communality was 0.63 in the full sample and was even higher in the subsample (0.71). The exception to this pattern of uniformly adequate communalities was the relation between latent mental health and suicide rate in the full sample (factor loading = −0.41; **Figure 4**). Suicide rate was retained in this model, however, in order to facilitate comparison between the full and subsamples (in **Figure 5** the factor loading is −0.65) and because a loading of −0.41 seemed large enough to be of theoretical interest, since both the loading and the error term indicate that

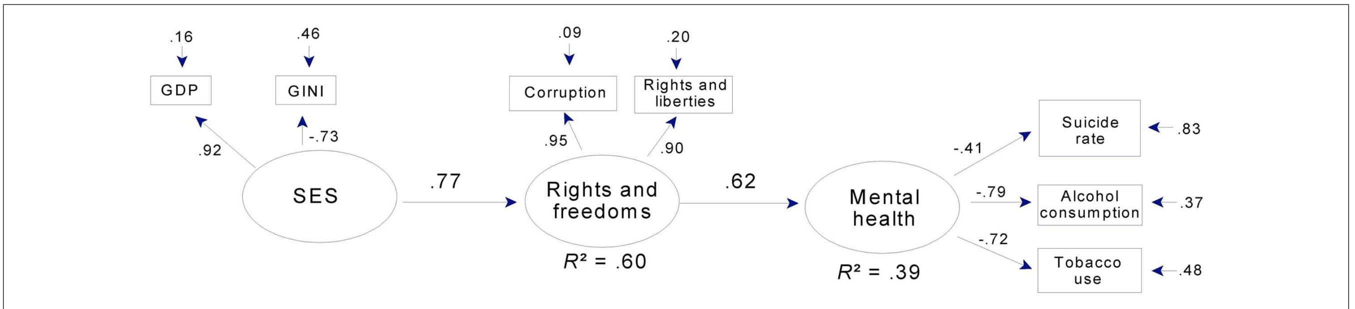

FIGURE 4 | Mental health, SES, and rights and freedoms: a path model for 34 countries. Note that corruption is reverse-scored, so that high scores = low levels of corruption. Rights and liberties = mean ratings for political rights and civil liberties (see text). Gini: high scores = economic inequality. GDP = Gross domestic product per capita.

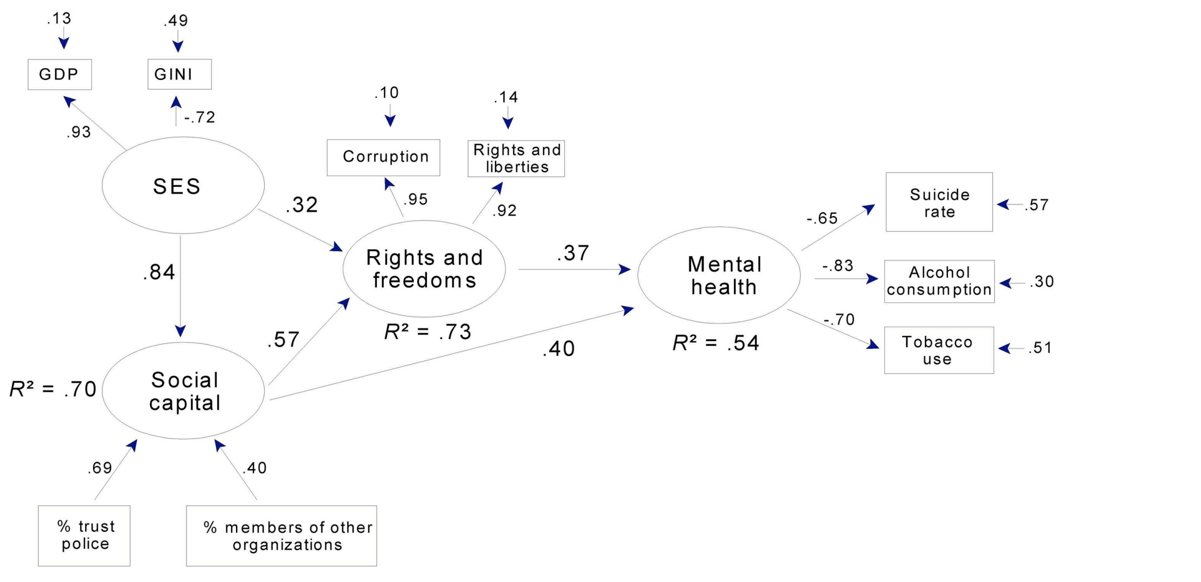

FIGURE 5 | Mental health, social capital, SES, and rights and freedoms: a path model for 23 countries. Note that corruption is reverse-scored, so that high scores = low levels of corruption. Rights and liberties = mean ratings for political rights and civil liberties (see text). Gini: high scores = economic inequality. GDP = Gross domestic product per capita. % trust police = % of WVS sample expressing trust in police. % members of other organizations = % of WVS sample who were active or inactive members in non-religious, non-labor organizations.

latent mental health in this model predicted 17% of the variance in suicide rate.

In contrast to levels of prediction and communality, levels of overall fit were moderate for both mental health models. The root mean square of the variance between the residuals of the manifest variables and the residuals of the latent variables [RMS COV (e,u); Falk and Miller, 1992], which reflects the amount of variance *not* accounted for by the model, was 0.12 for the full sample model and only slightly better in the subsample (0.11). Reflecting the fact that the models in **Figures 4** and **5** specify most of the available paths, these RMS COV (e,u) values were close to those for the corresponding full models (that is, models that have all possible paths specified). They also represent a substantial improvement over the corresponding null models (that is, models in which no paths are specified). For these null models, RMS COV (e,u) was 0.23 and 0.24, respectively, for the full and subsamples. Thus, while the overall levels of fit were moderate at 0.11 and 0.12, this represents a substantial improvement over the respective null alternatives.

In both mental health models, latent SES accounted for over 80% of the variance in GDP and more than half the variance in Gini scores. This latter pattern was also seen in the models for physical health (**Figures 6** and **7**). Hence, across all models, higher SES indicated higher per capita GDP and less economic inequality.

Latent rights and freedoms were strongly related to corruption and political rights and civil liberties, as indicated by factor loadings greater than 0.90 in all four models. Corruption was reverse-scored, so that higher values and positive factor loadings indicate lower levels of corruption. Thus, in all path models, high scores on rights and freedoms indicate low levels of corruption and high levels of political rights and civil liberties.

For both mental (**Figure 5**) and physical health (**Figure 7**), latent social capital was indexed primarily by the proportion of

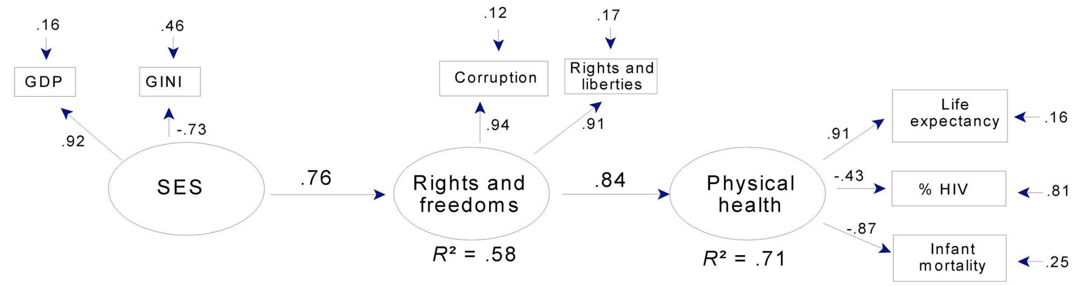

FIGURE 6 | Physical health, SES, and rights and freedoms: a path model for 34 countries. Note that corruption is reverse-scored, so that high scores = low levels of corruption. Rights and liberties = mean ratings for political rights and civil liberties (see text). Gini: high scores = economic inequality. GDP = Gross domestic product per capita.

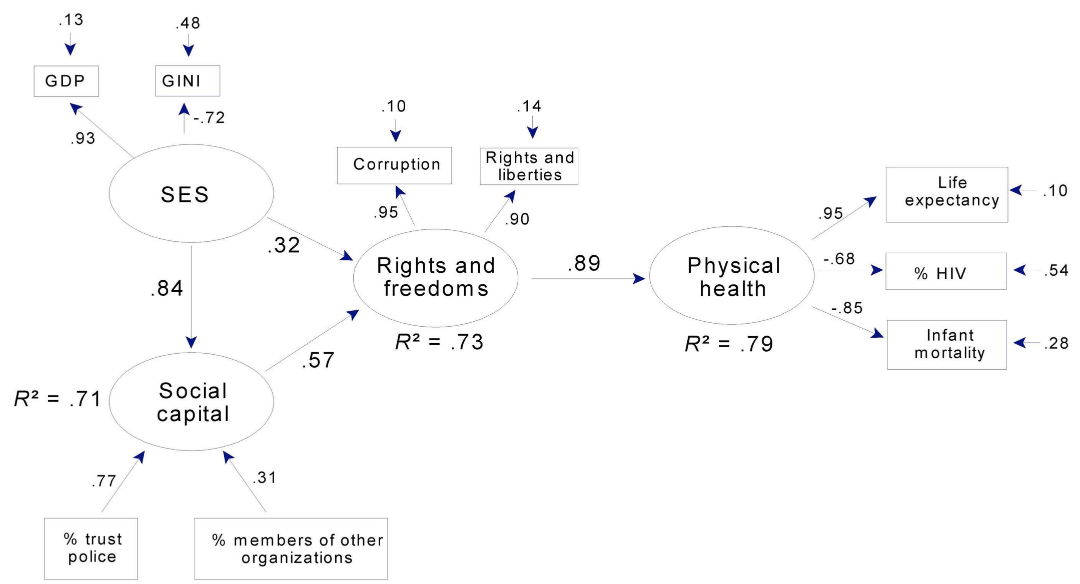

FIGURE 7 | Physical health, social capital, SES, and rights and freedoms: a path model for 23 countries. Note that corruption is reverse-scored, so that high scores = low levels of corruption. Rights and liberties = mean ratings for political rights and civil liberties (see text). Gini: high scores = economic inequality. GDP = Gross domestic product per capita. % trust police = % of WVS sample expressing trust in police. % members of other organizations = % of WVS sample who were active or inactive members of non-religious, non-labor organizations.

the WVS sample indicating trust in the police force, and to a lesser extent, by the proportion belonging to non-church, non-labor organizations. Their relative importance is indicated by their respective loadings or weights which are equivalent to standardized regression coefficients in a multiple regression analysis and, therefore, index or predict the outcome without presumptions about their causal origins or relations. In contrast, loadings for the "outer directed" latent variables (SES, rights and freedoms, health) are factor loadings – the correlations between the manifest variables and the latent variables they define. Thus, each latent variable summarizes the variance shared across the set of manifest variables from which it is derived, and this variance is shared presumably because the manifest variables share underlying causes (Shipley, 2000). For example, those factors (whatever they are) that affect physical health in a given society have an impact on both life expectancy and infant mortality, which consequently are correlated. In contrast, the manifest variables associated with an "inner directed" construct like social capital are not presumed to share variance because they share underlying causes. Therefore, other measures of social capital (e.g., trust in government, press, political parties) were not included in the models, as they were not related to rights and freedoms independently of trust in the police and rate of membership in other organizations due to their small weights (less than 0.30) in the preliminary path models.

In the models for mental (**Figure 5**) and physical health (**Figure 7**), social capital and SES were strongly related in that they shared over two-thirds of their variance. Although there are no clear theoretical grounds for specifying the causal influences between these two constructs, we chose to include a provisional path from SES to social capital, as discussed later. Omitting a path altogether would imply that there are *no* causal relations between social capital and SES, which is not plausible; and empirically,

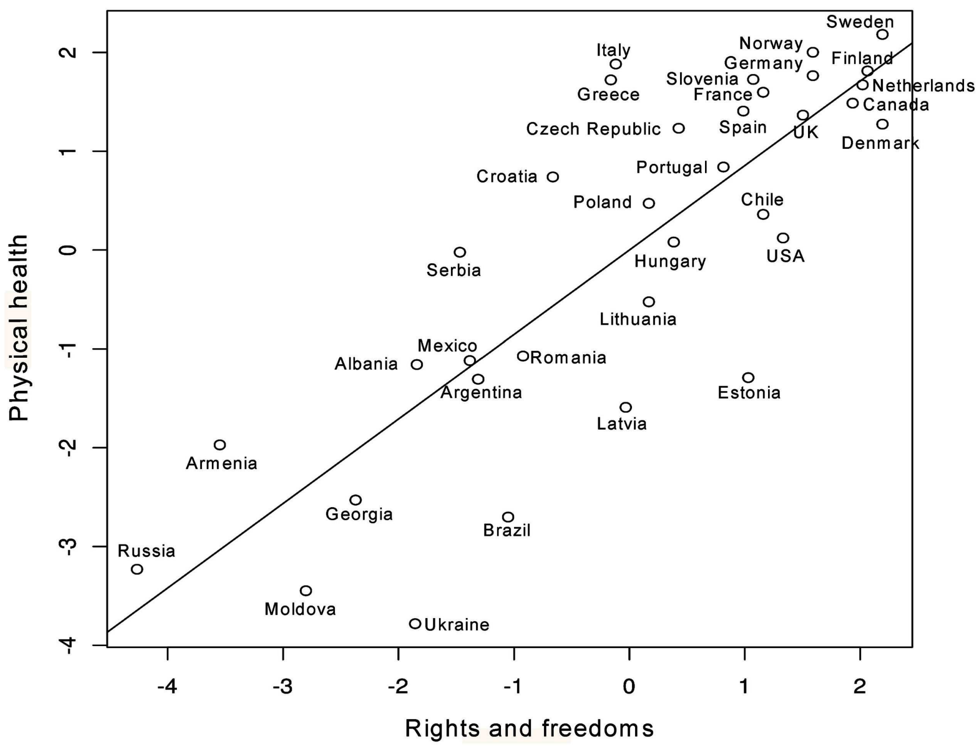

FIGURE 8 | Scatterplot of rights and freedoms versus physical health.

omitting a path between these two constructs results in a substantial increase in the model's lack of fit, increasing RMS COV (*e*,*u*) for mental health, for example, to 0.14 from 0.11. Thus, the existence of a path is indicated, even if its direction is uncertain.

Overall, the path models in **Figures 4** and **5** indicate strong relations between rights and freedoms and mental health, especially as indexed by lower alcohol consumption and reduced daily tobacco use. **Figure 5** indicates that social capital is also a strong predictor of mental health, both directly and indirectly through rights and freedoms. SES is an important component of both models, strongly related to social capital, directly and indirectly related to rights and freedoms, and through rights and freedoms and social capital to mental health.

Physical health, like mental health, was strongly predicted in the full sample (**Figure 6**), where rights and freedoms predicted over two-thirds of the variance in a latent variable aggregating life expectancy, infant mortality, and (to a lesser extent) HIV prevalence. In the subsample, rights and freedoms together with social capital predicted over three-quarters of the variance in physical health (**Figure 7**). In both models, as in the mental health models, well over half the variance in rights and freedoms was predicted by SES or by SES together with social capital; and SES strongly predicted social capital.

In addition to strong relations between latent variables, the final models for physical health adequately summarized the manifest variables. Mean communality was 0.69 in the full sample model and was even higher in the subsample model (0.76). The exception to this pattern of uniformly adequate communalities was the relation between latent physical health and HIV prevalence in the full sample (factor loading = −0.43; **Figure 6**). Prevalence of HIV was retained in this model for the same reasons that suicide rate was retained in the model for mental health, that is, to facilitate comparison between the full and subsample models (in **Figure 7** the factor loading for HIV prevalence is −0.68) and because a loading of −0.43 was large enough to be of theoretical interest. Both the loading and the error term indicate that latent physical health predicted 19% of the variance in HIV prevalence.

As with levels of prediction and average communality, levels of overall fit were adequate for both physical health models. RMS COV (*e*,*u*) was 0.07 for both the full and subsample models. Reflecting the fact that the models in **Figures 6** and **7** specify most of the available paths, these RMS COV (*e*,*u*) values were close to those for the corresponding full models. They also represent a substantial improvement over the corresponding null models for the full and subsamples, which had RMS COV (*e*,*u*) values of 0.28 and 0.27, respectively.

In summary, the path models in **Figures 6** and **7** indicate very strong relations between rights and freedoms and physical health, especially as indexed by life expectancy and low infant mortality. **Figure 7** indicates that social capital had an important indirect relation to physical health through rights and freedoms. Finally, as in the models for mental health, SES was related to both social capital and rights and freedoms, and thus had, like social capital, important indirect links to physical health.

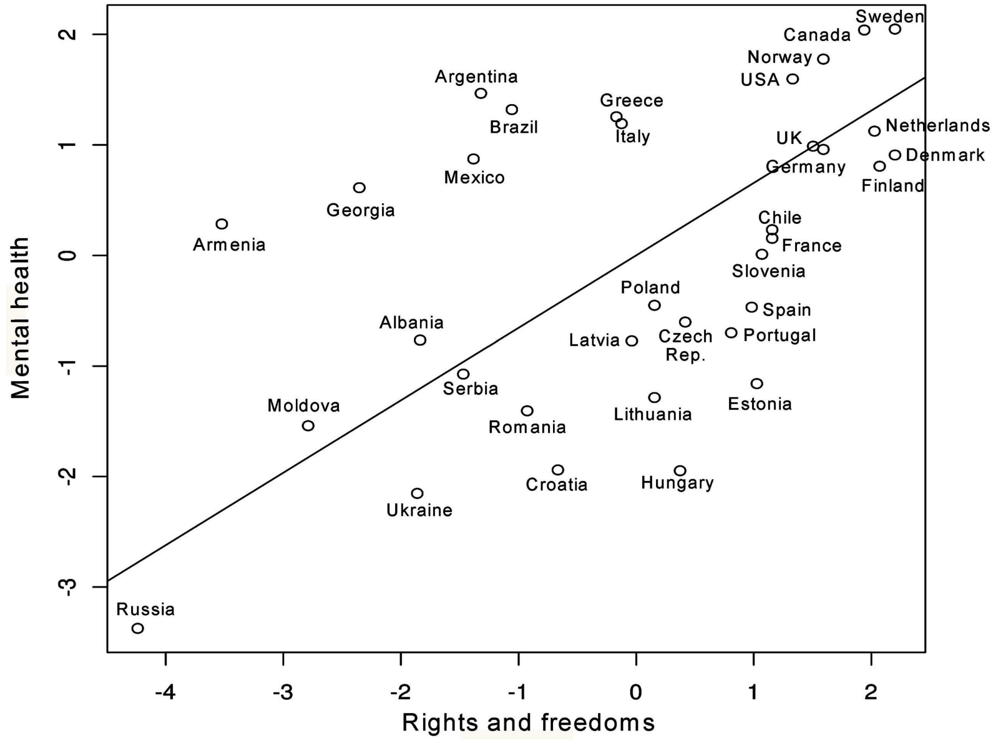

FIGURE 9 | Scatterplot of rights and freedoms versus mental health.

THE RIGHTS AND FREEDOMS GRADIENT OF HEALTH

Our results suggest that rights and freedoms have a prominent role in the determination of health outcomes, accounting for most of the association between SES and health, both physical and mental. In addition, rights and freedoms accounted for most of the association between social capital and physical health. Also, the positive effect of social capital on mental health was partially accounted for by rights and freedoms. These important and novel observations provide evidence for a rights and freedoms gradient in health, as represented in **Figures 8** and **9**. What **Figures 8** and **9** indicate, for the most part, is that in countries where more rights and freedoms exist, children, youth, and adults have better physical and mental health outcomes. However, in a few exceptions, a small number of countries deviate from the gradient line, indicating either better or worse health outcomes than expected. To determine which country fell off the diagonal line we calculated z scores and looked for countries whose values significantly deviated from 0 (any value of more than 1.96 was considered significant at 0.05; and values of 1.645 significant at 0.10). This analysis led us to the identification of: (1) resilient countries such as Italy and Greece with better physical health outcomes and Argentina with better mental health outcomes than otherwise expected based on their scores in rights and freedoms; and (2) vulnerable countries, such as Ukraine, Estonia, and Brazil with worse off outcomes in physical health, and Hungary with worse off outcomes in mental health than otherwise expected based on their scores in rights and freedoms. The implications of this emerging evidence of a rights and freedoms gradient of health, and its interpretation in the context of cross-national research are discussed below.

DISCUSSION

In conducting this study, we set out to apply the WHO framework of social determinants (**Figure 1**) of health to a cross-national sample of 34 countries from Europe, North and South America, and the South Caucasus for which we had mental and physical health outcome data. The full sample of 34 countries, for which social capital data were unavailable, indicated significant positive effects of rights and freedoms on mental and physical health. We replicated the same models on a subsample of 23 countries for which we also had social capital data. Both samples contained developed countries and countries in transition. We anticipated that our results would be congruent with the WHO framework of social determinants (**Figure 1**). The WHO framework (**Figure 1**) associates increased rights and freedoms with increased wealth and social equality, which in turn promotes better health. Based on the WHO framework (**Figure 1**), we also anticipated that social capital and civil society would moderate the effect of SES. As earlier noted, this WHO framework (**Figure 1**) encapsulates the "*social inequality*," "*civil society and social capital*," and "*rights and liberties*" arguments. Therefore, similar to previous studies, we found that SES and social capital played important roles in the determination of health. However, we were surprised to discover that rights and freedoms mediated these effects. Our findings showed that the effects of SES and social capital on physical health were fully mediated through democratic rights and freedoms. However, the mental health model indicated that rights and freedoms completely mediated the effects of SES and only partially mediated the effects of social capital. The models suggest different origins for mental and physical health outcomes. We named the models, the "*rights and freedoms gradient of health*" to acknowledge this latter construct's crucial role in determining health outcomes. To this end, "*rights and freedoms*" denotes political rights, civil liberties, and freedom from corruption. It is likely that our findings may have come to light because, as far as we know, this is the first study to simultaneously examine the effects of SES, social capital, and rights and freedoms on health outcomes using pathways models.

The mediating role of rights and freedoms has significant implications that deserve further discussion. Most previous studies investigating the effects of rights and freedoms focused on one or two physical health variables – usually life expectancy or infant mortality rates (Dasgupta, 1990; Altman and Castiglioni, 2009). The present study, instead, incorporated three variables of mental health and three of physical health outcomes. Our results are also consistent with previous findings that suggest that SES (Wilkinson and Picket, 2009), social capital (Elgar, 2010), and democratic rights and freedoms (Dasgupta, 1990; Altman and Castiglioni, 2009) are all independently associated with better health outcomes. First, a large body of evidence in support of the "*social inequality argument*" contends that increasing a nation's SES, in terms of overall wealth (Wickrama and Mulford, 1996) with an equitable distribution of wealth, is associated with better health outcomes (Wilkinson and Picket, 2009). Second, many previous studies support the "*rights and liberties argument*" in that democratic rights and freedoms positively affect physical health, such as decreasing infant mortality rates and increasing life expectancies (Dasgupta, 1990; Franco et al., 2004; Altman and Castiglioni, 2009). However, few studies have examined the effects of rights and freedoms on mental health. One study, though, has shown that when civil liberties increase, suicide rates decrease (Jungeilges and Kirchgässner, 2002). Third, cross-national evidence from the "*civil society and social capital argument*" suggests that social capital is positively related to better health outcomes (Elgar, 2010). Therefore, our findings are consistent with past studies that independently associate SES, rights and freedoms, and social capital with increased health performance. Unique to the present study is that our findings place these latter constructs into relative context to one another.

Over two decades ago, Dasgupta (1990) refuted the argument that poorer countries cannot afford the "luxury" (p.4) of rights and freedoms. Dasgupta further argued that when individuals have greater rights and freedoms, they also perform better regarding health. In this context, rights and freedoms are thought to permit citizens to exert pressure for beneficial social policy (Korpi, 1989). An implication of this study is that its results support the notion that rights and freedoms may be essential social conditions to support not only child survival, but also child and youth development, as rights and freedoms are reflected in population indicators of mental and physical health outcomes over the life-course.

Our findings suggest that to improve population health, countries must strive to integrate efforts addressing all of these three critical factors, concurrently: socioeconomic conditions, civil society and social capital, and rights and freedoms. This concept has been recognized by the United Nations Development Program (UNDP) in developing their Human Development Index, a composite score that measures life expectancy, education and national wealth, "to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone" [United Nations Development Programme (UNDP), 2011]. Specifically, the democracy theme of the 2002 UNDP report [United Nations Development Programme (UNDP), 2002] recognized the importance of linking democratic rights and freedoms, human development, and health. Yet, the UNDP does not include a measure of these rights and freedoms in their human development index as their 2002 report notes that these concepts "are difficult to measure appropriately" (p. 53).

In addition, the 2002 UNDP report states that civil society development is instrumental in building democracy. Yet, the report does not integrate civil society into their concept of mutually reinforcing capabilities (p. 53) which included links between rights and freedoms, SES, and health-education. A similar sentiment was echoed in the WHO's framework on the social determinants of health [World Health Organization (WHO), 2010] which noted that "social capital occupy a conspicuous (and contested) place in discussions of SDH (social determinants of health)" (p. 7) because "focus on social capital, depending on interpretation, risks reinforcing depoliticized approaches to public health" (p. 7). Our results suggest that civil society (term used by UNDP), or by extension social capital (term used by WHO), must also be integrated into frameworks and concepts that advance health outcomes. In the context of the UNDP and WHO reports, social capital and civil society are similar concepts. As previously noted, social capital can be defined as the associations or networks that generate the cooperation and trust necessary for the realization of common goals (Putnam, 2000). Civil society can be described as the interactions of citizens "which has a life of its own, which is distinctively different from the state and largely autonomous from it" to promote the collective interest (Shils, 1991). From these perspectives, the terms social capital and civil society can both be construed as reflecting power that originates with citizens and strengthens democratic rights and freedoms.

The relationship between social capital and SES was more difficult to interpret. We chose to denote SES as leading to social capital. This decision was somewhat arbitrary as reversing the relation in enlisting social capital leading to SES in the pathway model is equally statistically equivalent. Future research is warranted in uncovering the path. In any event, our findings suggest that social capital and SES are both necessary for the development of rights and freedoms, and consequently health. In this respect, past research has shown that increasing only SES (in terms of GDP per capita) does not lead to better health outcomes (Altman and Castiglioni, 2009).

Interestingly, our findings also suggest that despite their levels of rights and freedoms, some nations are more resilient than others, in terms of countries falling significantly above or below the regression line. For example, when comparing rights and freedoms versus physical health outcomes, Estonia, Ukraine, and Brazil are significantly below the regression line, while Italy and Greece fall significantly above the regression line. Comparatively for mental health, Argentina falls above the regression line and Hungary falls below. These findings raise a wide range of questions as to what might be at play in those resilient and vulnerable countries. Pertaining to resilience, possibilities might include regional variations that exist within a given country (e.g., differences between the north/south, east/west, rural/urban) or decentralization of health care administration and service provision as may be the case in Italy. Pertaining to vulnerability, ethnic fragmentation (Aghion et al., 2004), authoritarian regimes with an abundance of natural resources in poorer countries (Ross, 2001), and past histories of colonialization (Diamond et al., 1987) can impede democratization. Any such hindrance could plausibly have important health implications, given the results of this study. For example, Ukraine was under colonial rule for centuries (Subtelny, 2009) and suffered from a Soviet-orchestrated genocide in 1932–1933 that claimed the lives of several million Ukrainians (Naimark, 2010). The genocide resulted in a decades-long, decreased life expectancy for survivors and their offspring after the genocidal period (Meslé et al., 2012).

Concerning approaches to improve health performance, our model is also consistent with past research on development aid. Specifically, Kosack (2003) concluded that development aid better effects improvements in health (i.e., life expectancy) when combined with increases in rights and freedoms. Kosack further noted that when rights and freedoms are minimal, as in autocracies, aid is ineffective. These latter aid findings are consistent with our model that suggests rights and freedoms provide the core that successively impacts health. Further, our research also contends that improvements in SES and social capital are foundational prerequisites for the growth of rights and freedoms. By extension, our results suggest that development aid targeting improvements in SES and social capital would also benefit growth in rights and freedom. The latter would, then, improve mental and physical health outcomes.

Our results also have implication concerning current thought on mental health trends. For example, Thachuk (2011) wrote a critical analysis of the recent trend to label mental illness as being exclusively biological in origin. Our findings suggest that mental health (such as suicide, alcohol and tobacco dependencies), to a large extent, also has strong social determinants.

Lastly, our models hold for the variables and countries used in this study. As our sample contained countries located in Europe, North and South America, and the South Caucasus, further study of nations from other regions of the world and other indicators of mental and physical health is necessary. Determining if an additional step, like good governance, exists between rights-freedoms and health outcomes is also warranted. As our findings are cross-sectional, they do not imply causation. However, our results are consistent with studies that have demonstrated causation (Dasgupta and Weale, 1992) in rights and freedoms leading to better health outcomes.

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Hippocampal volume varies with educational attainment across the life-span

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Socioeconomic disparities—and particularly differences in educational attainment—are associated with remarkable differences in cognition and behavior across the life-span. Decreased educational attainment has been linked to increased exposure to life stressors, which in turn have been associated with structural differences in the hippocampus and the amygdala. However, the degree to which educational attainment is directly associated with anatomical differences in these structures remains unclear. Recent studies in children have found socioeconomic differences in regional brain volume in the hippocampus and amygdala across childhood and adolescence. Here we expand on this work, by investigating whether disparities in hippocampal and amygdala volume persist across the life-span. In a sample of 275 individuals from the BRAINnet Foundation database ranging in age from 17 to 87, we found that socioeconomic status (SES), as operationalized by years of educational attainment, moderates the effect of age on hippocampal volume. Specifically, hippocampal volume tended to markedly decrease with age among less educated individuals, whereas age-related reductions in hippocampal volume were less pronounced among more highly educated individuals. No such effects were found for amygdala volume. Possible mechanisms by which education may buffer age-related effects on hippocampal volume are discussed.

Keywords: socioeconomic status, SES, education, hippocampus, amygdala, brain, neuroanatomy, brain reserve

INTRODUCTION

Socioeconomic disparities are associated with remarkable differences in cognition and behavior (Noble et al., 2005, 2007; Farah et al., 2006; D'Angiulli et al., 2008; Gianaros et al., 2008; Hackman and Farah, 2009; Kishiyama et al., 2009; Stevens et al., 2009; Raizada and Kishiyama, 2010), with ramifications for physical and mental health across the lifespan (Brooks-Gunn and Duncan, 1997; McLoyd, 1998; Gianaros and Manuck, 2010).

Socioeconomic status (SES) is typically characterized by multiple factors, including educational attainment, occupation, and income level (McLoyd, 1998). In childhood, SES is typically quantified by measuring parental levels of these indicators. In contrast, studies of SES among adults more commonly focus on an individual's *own* socioeconomic position (Stern, 2002; Scarmeas et al., 2006; Gianaros et al., 2007a). Adult socioeconomic attainment may influence cognition across the life-course independently of childhood SES (Turrell et al., 2002), and the effects of childhood SES may operate on adult cognitive achievement indirectly through adult socioeconomic position (Singh-Manoux et al., 2005).

Different components of SES may operate differentially on specific life outcomes, via different mechanisms (Duncan and Magnuson, 2012; Noble et al., 2012). However, across the lifespan, educational attainment is arguably the single socioeconomic variable that best predicts both cognitive and neural outcomes. For example, in adulthood, an individual's level of education has been related to an array of cognitive skills, including processing speed, working memory, verbal fluency, and episodic memory (Zahodne et al., 2011). Similarly, in healthy elderly individuals, some investigators have reported associations between higher education and increased cortical thickness across a large number of cortical regions (Liu et al., 2012) although other studies have failed to find similar relationships (Seo et al., 2011).

Educational attainment may have differential effects on particular brain regions over the life course. Of course, SES in general, and educational attainment specifically, is a marker for a broad conglomerate of experiences and exposures. Many environmental factors have been shown to affect regionally specific brain development (Rosenzweig, 2003; McEwen and Gianaros, 2010), and thus are likely candidates in mediating the links between educational disparities and specific neurocognitive outcomes. For example, lower levels of education have been associated with increased exposure to numerous life stressors, including uncertainty about material resources such as food or clothing; chaotic households; and exposure to violence (Evans, 2004). Exposure to stressors may in turn relate to structural differences in specific brain regions that are particularly responsive to stress, including the hippocampus (Buss et al., 2007; Felmingham et al., 2009; McEwen and Gianaros, 2010; Tottenham and Sheridan, 2010; Teicher et al., 2012) and the amygdala (McEwen and Gianaros, 2010; Tottenham and Sheridan, 2010). However, results have been mixed concerning the degree to which educational attainment is itself directly associated with measurable anatomic differences in these two neural regions.

One recent study found that higher educational attainment was associated with decreased white matter mean diffusivity in the hippocampus (Piras et al., 2011). However, other studies have failed to find effects of educational attainment on hippocampal volume (Kidron et al., 1997; Hanson et al., 2011; Noble et al., 2012) or cortical thickness (Liu et al., 2012). One recent study found that childhood SES, as operationalized by adult recall of childhood home conditions and paternal occupation, predicted adult hippocampal volume, whereas adult educational attainment did not (Staff et al., 2012). Further, one study of postmenopausal women found that, although hippocampal volume varied as a function of perceived stress, this effect was not accounted for by differences in education levels (Gianaros et al., 2007b).

In the amygdala, some investigators have reported positive relationships between educational attainment and regional volume (Laakso et al., 1995; Noble et al., 2012) while others have not (Gianaros et al., 2007b; Hanson et al., 2011). Other studies have reported significant associations between levels of education (Dannlowski et al., 2012) or subjective social status (Gianaros et al., 2008; Muscatell et al., 2012) and amygdala function.

One way to reconcile these seemingly disparate findings is to note that, although a number studies have examined the effects of educational disparities on regional brain structure, the majority have done so within a relatively narrow age range. To our knowledge, no study has assessed whether any effect of educational attainment on these structures may be moderated by the age of participants across the lifespan. As the absence of a main effect is uninterpretable in the presence of an interaction (Pedhazur, 1997a), this represents a significant gap in the literature.

The theory of "brain reserve" suggests that higher levels of education may confer benefits in brain structure or function that may buffer against age-related changes (Stern, 2002, 2006). Early exposure to cognitively stimulating experiences may be protective against later insult (Holt and Mikati, 2011). For example, one recent study found that, while greater educational attainment did not protect individuals from neuropathology, it did reduce the risk of developing clinical dementia relative to less educated individuals with similar degrees of pathology (Brayne et al., 2010). In that study, education was also associated with brain weight, suggesting that the compensatory influence of education may be mediated by increased regional or global brain volume.

Based on this reasoning, we hypothesized that educational attainment may be associated with regional volumetric differences in the hippocampus and amygdala across the life-course. Further, we predicted that the effects of educational attainment would not be consistent across all ages, but rather would be most pronounced in buffering against age-related decline. To test these hypotheses, we employed structural magnetic resonance imaging (MRI) to assess regional hippocampal and amygdala volume in an educationally diverse sample of adults across a seven-decade age range.

MATERIALS AND METHODS

SUBJECTS

Subjects were compiled from the Brain Resource International Database, accessed via the independently governed 501(c)(3) BRAINnet Foundation (http://www.BRAINnet.net). Wave I data from this standardized database comprise demographic, self-report, physiologic, and neuroimaging data on healthy participants ranging in age from 7 to 87, collected from six primary sites throughout the world (Gordon et al., 2005; Grieve et al., 2005). For the current study, participants included the 275 individuals (152 female) who were 17 years of age or older (average age 39.7 years, s.d. 17, range 17–87), and for whom both years of educational attainment as well as hippocampal and amygdala regional volumes were available (see **Table 1**). The majority of the sample self-identified as having European ancestry (74%). Additionally, 5.1% of the sample self-identified as having African ancestry, 5.8% were of Asian ancestry (including Middle Eastern or Indian subcontinent), 0.4% were Indigenous Australian, 0.4% were Pacific Islander, 8.4% identified as mixed race/ethnicity, and 5.8% preferred not to answer.

This participant cohort represents a community sample found in the major cities of Australia with no known bias in region-wise education or distribution of educational attainment. Although individuals from lower socioeconomic backgrounds are often difficult to recruit to participate in research studies, educational attainment of the sample spanned a wide range (mean 14 years, s.d. 3.1, range 3–18 years). This range of education is due in part to the fact that, across Australia, educational attainment is fairly diverse, with approximately 25% of individuals not earning a high school diploma, approximately 45% of individuals completing high school only, and approximately 30% completing some type of post-secondary education (Pink and Australian Bureau of Statistics, 2010).

MRI data sets came from two imaging sites: Westmead Hospital (Sydney, Australia) and Wakefield Imaging (Adelaide, Australia). All participants in the study were recruited from the general population in the Sydney and Adelaide urban and suburban areas within Australia through standard recruitment procedures (e.g., community advertisements). Cross-site reliability has been established (Grieve et al., 2005). As age and educational attainment are nearly perfectly correlated in younger children, children in the database under 17 years old were excluded from the analysis, as it would be impossible to de-confound the effects

Table 1 | Demographics of sample.

Education level	High school or less	Some college	College and up	Total
N	89	83	103	275
Age:				
Mean (s.d.)	48 (19)	35 (16)	36 (13)	39.7 (17)
Sex	49 female, 40 male	42 female, 41 male	83 female, 89 male	152 female, 123 male

of age and education among this group. By the late teenage years, however, it is possible to distinguish the effects of age and education. For example, among the 35 teenagers in the sample aged 17–19, the range of education spanned from 11 (less than high school) to 16 years (college degree). This is possible, in part, because not all individuals complete high school and/or go on to college, and conversely, because most Australian universities have mechanisms for accepting talented youngsters to university early, before the completion of high school (Victorian Government Department of Education and Early Childhood Development, 2010).

Participants completed WebQ, a standardized computer-based battery of questionnaires that assess medical history, demographics, and psychological function, including current or lifetime diagnosis of neurological and psychiatric (Axis 1) conditions (Heatherton et al., 1991; Trzepacz and Baker, 1993; Bush et al., 1998; Spitzer et al., 1999; Breslau and Kessler, 2001; Hickie et al., 2001) (for more information see Gatt et al., 2009; Williams et al., 2009). All participants in the database were excluded from further participation if they had history of brain injury, significant medical, neurological or psychiatric conditions, and/or drug or alcohol addiction. Individuals with first-degree family members with an Axis I disorder were also excluded. No specific screening for neurodegenerative disorders was performed. However, a subset of participants completed a test of memory performance, as described below.

All participants provided informed consent in accordance with the National Health and Medical Research Council of Australia guidelines. Participation was voluntary and participants were reimbursed to cover cost for their time and travel to the research center.

MEMORY TESTING

One hundred fourteen of the participants had complete data on a Memory Recall and Recognition test. This test is a variant of the Rey Auditory Verbal Learning and Memory task (Rey, 1964; Geffen et al., 1990), commonly used to provide measures of auditory-verbal learning, recall, and recognition. Briefly, the participant is presented with a sequence of 12 words binaurally via headphones, 1 s at a time. The participant is instructed to say back as many of the words as they can remember from the list, in any order. This procedure is then repeated three more times, with the same instructions. The total number of words recalled during these four trials is recorded. The participant is then presented with a second list of words (which are neither semantically nor phonetically related to the first list) and asked to say back as many of these as can be remembered (Distractor Trial). Immediately following this trial, the participant is asked to recall as many words as can be remembered from the first list (Immediate Recall Trial). Approximately 25 min later, after completing a number of other tests in the battery, the participant is again asked to recall as many words as possible from the first list (Delayed Recall Trial). The subject is then presented one at a time with a series of 24 words on the computer screen (Recognition Trial). Half of these words are the words from the first list; the remaining words are new words. The words are in fixed, pseudorandom order. Following each word, the participant is required to touch a "Yes" or "No" button on the touchscreen according to whether or not the word was in the first list.

MRI SCAN ACQUISITION

MRI was conducted on a 1.5 Tesla Siemens Sonata system at Westmead Hospital, Sydney and a 1.5 Tesla Siemens Sonata at Perrett Imaging, Flinders University, Australia. The MRI protocol included a 3-D T1-weighted image acquired in the sagittal plane using an MPRAGE sequence (TR = 9.7 ms; TE = 4 ms; echo train 7; flip angle = 12°; TI = 200 ms; NEX = 1). A total of 180 1 mm slices (without gap) were acquired with a 256 × 256 matrix with an in plane resolution of 1 mm × 1 mm. Approximately 1% of the MRI data were excluded from the overall database due to MRI technical acquisition errors/artifact.

MRI ANALYSIS

Volumetric segmentation was performed on the 3D T1-weighted structural images with the FreeSurfer image analysis suite (version 4.3) (http://surfer.nmr.mgh.harvard.edu/), which has been shown to be comparable in accuracy to manual labeling (Fischl et al., 2002). The technical details of these procedures are described in detail elsewhere (Dale et al., 1999; Fischl et al., 1999; Fisher and Defries, 2002; Grieve et al., 2011). Volumetric measurements of the hippocampus and the amygdala were generated with FreeSurfer's automatic quantification of subcortical structures, which assigns a neuroanatomical label to each voxel in an MRI volume based on probabilistic information estimated from a manually labeled training set (see **Figure 1**). The classification technique employs a non-linear registration procedure that is robust to anatomical variability, as described in detail elsewhere (Fischl et al., 2002). Anatomically labeled structures were manually inspected for accuracy, and corrected if necessary. Total brain volumes, which were used as a covariate in the statistical analyses, were also generated automatically with the FreeSurfer processing stream.

STATISTICAL ANALYSES

To assess whether educational attainment influences regional brain volume across the life-span, we conducted a series of regression analyses, with total hippocampal volume or amygdala volume as the dependent variable, and years of educational attainment as the independent variable of interest. Analyses included age, sex, and total brain volume as covariates. We hypothesized that educational attainment would account for variation in regional brain volume, adjusting for age, sex, and total brain volume. Additionally, we examined the extent to which age-related regional brain volumetric differences would be modified by educational attainment. Specifically, we predicted a significant education × age interaction, such that age-related decreases in regional brain volume would be less steep among more highly educated individuals.

For ease of presentation, results in tables and figures are at times presented using categorical bins of age and educational attainment. However, unless otherwise noted, statistical analyses considered age in years and years of education as continuous variables, to take advantage of the full level of detail provided by the dataset.

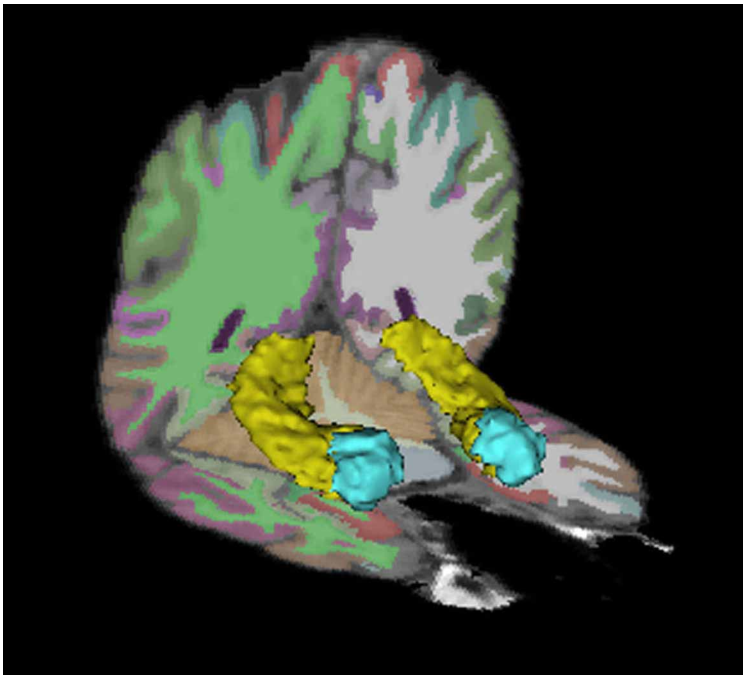

FIGURE 1 | Hippocampus and amygdala regions of interest. The bilateral hippocampi are depicted in yellow. The bilateral amygdalae are depicted in blue.

RESULTS

REGIONAL VOLUMETRIC DATA

Table 2 shows hippocampal and amygdala volumetric data, broken down by age and gender categories.

Both hippocampal and amygdala volumes were normally distributed across the sample, without outliers (Hippocampus: skewness $= -0.089$ (SE 0.147), kurtosis $= 1.175$ (SE 0.293), Kolmogorov–Smirnov normality statistic $= 0.041$, $p = 0.2$; Amygdala: skewness $= 0.306$ (SE 0.147), kurtosis $= 0.618$, (SE 0.293), Kolmogorov–Smirnov normality statistic $= 0.041$, $p = 0.2$).

MAIN EFFECTS—HIPPOCAMPUS

Initial bivariate correlations showed that age was significantly negatively associated with hippocampal size across the entire age range ($r = -0.374$; $p < 2.1 \times 10^{-11}$). However, the data were better fit by a quadratic function for age ($r = -0.402$; $p < 4.3 \times 10^{-12}$), reflecting the fact that hippocampal volume tends to increase until approximately age 30, at which point hippocampal volume tends to decline (Grieve et al., 2011). Age^2 was therefore included as a regressor in all models below.

Additionally, across the entire age range, educational attainment was positively and linearly associated with hippocampal size ($R = 0.236$; $p < 7.9 \times 10^{-5}$). When adjusting for age, sex, and total brain volume, however, the main effect of educational attainment did not account for significant unique variance in total hippocampal volume (Beta $= 0.078$; $p < 0.076$), left hippocampal volume (Beta $= 0.086$; $p < 0.053$), or right hippocampal volume (Beta $= 0.065$; $p < 0.15$).

Table 2 | Hippocampus and amygdala volume, by age and sex.

	Hippocampal volume, mm^3 mean (s.d.)	Amygdala volume, mm^3 mean (s.d.)
Males <35	9004 (871)	3421 (352)
Males 35 and up	8187 (1063)	3103 (455)
Females <35	8248 (711)	2968 (306)
Females 35 and up	7893 (830)	2847 (329)

MAIN EFFECTS—AMYGDALA

Similar to the findings in the hippocampus, bivariate correlations revealed a significant negative association between amygdala volume and age ($r = -0.239$; $p < 2.9 \times 10^{-5}$), with the data best fit by a quadratic function for age ($r = -0.254$; $p < 2.04 \times 10^{-5}$) (Grieve et al., 2011).

A significant linear association between amygdala volume and educational attainment was also observed ($r = 0.154$; $p < 0.01$). Again, however, the main effect of educational attainment on total amygdala volume was no longer significant when adjusting for age, sex, and total brain volume (Beta $= 0.029$; $p = 0.515$). Nor was this effect significant when the left (Beta $= 0.073$; $p < 0.094$) or right (Beta $= -0.016$; $p < 0.744$) amygdala were considered separately.

AGE BY EDUCATION INTERACTIONS

Of interest next was the extent to which the effect of age on regional volume varied by an individual's educational attainment. To assess this hypothesis, models above were extended to include terms for an age × education interaction. We first assessed the hippocampus. A significant age × education interaction was present (R^2 change = 0.021, Beta =0.498 $p < 0.001$), suggesting that the effect of age on hippocampal volume is not constant across all levels of educational attainment. This finding is portrayed in **Figure 2**, where it can be seen that the age-related decline in hippocampal volume is moderated by education. In this figure, the data are divided according to median split of individuals by age and education. There is no difference in hippocampal size by education among individuals younger than 35 years of age [$t_{(136)} = -0.636$; $p = 0.53$]. However, among individuals older than 35 years, there is a highly significant difference in hippocampal size, with more highly educated individuals having larger hippocampi [$t_{(135)} = -5.6$; $p < 0.0001$].

When considered separately, both left and right hippocampi showed a similar interaction (left hippocampus: Beta = 0.508, $p < 0.001$; right hippocampus: Beta = 0.462, $p < 0.002$).

Figure 3 shows a "dose-dependent" effect of education: The observed age-related volumetric decreases in hippocampal volume are greater among less educated individuals relative to more highly educated individuals. Less difference in hippocampal volume is seen with age among the highest educated individuals.

Of note, there was a wide span of educational attainment across the entire age range, with the educational spectrum represented across each age range, from young adults to elderly individuals (see **Table 1**). Nonetheless, there was a significant correlation between age and education ($r = -0.257$; $p < 0.0001$), such that older participants were on average less educated than younger participants. For this reason, we also examined the full model excluding "influential points" in this correlation. Influential points were identified using the standardized difference in beta, defined as the difference in the standardized regression coefficient as a result of deleting a particular case, divided by the standard error of this difference. Any value greater than $2/\sqrt{n}$ was excluded (Pedhazur, 1997b). Among the remaining 267 participants, the age × education interaction remained significant (Beta = 0.454; $p < 0.001$), suggesting that the moderating effect of education on age-related decreases in hippocampal volume is an accurate description of the sample, and not a spurious finding driven by the influence of a small number of subjects with extreme values. These 267 participants are represented in **Figure 3**.

No significant education × age interaction was observed in total amygdala volume, or left or right hemispheres considered separately, regardless of whether influential points were included or excluded, suggesting that the effect of age on amygdala volume is independent of educational attainment.

MEMORY TESTING

No specific clinical testing was done to assess whether participants may have had early signs of a neurodegenerative disease. However, the scores of the 114 participants who had valid data for the Memory Recall and Recognition test were extremely similar to

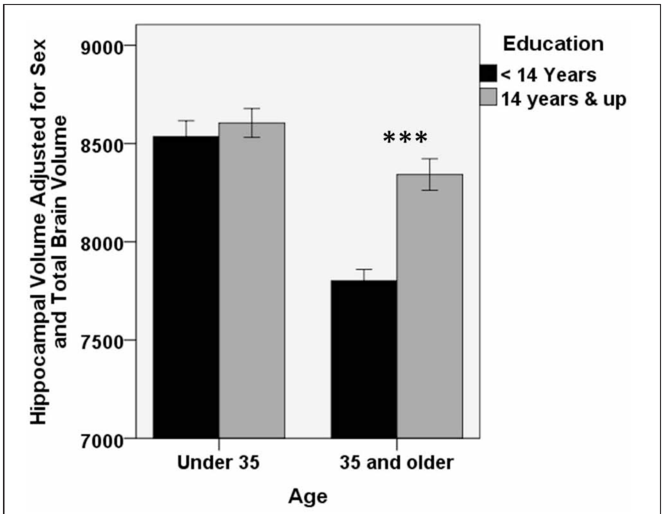

FIGURE 2 | Higher educational attainment buffers age-related decrease in hippocampal volume. A significant education × age interaction is present for hippocampal volume (Beta = 0.498 $p < 0.001$), such that age-related decline in hippocampal volume is smaller among individuals with higher educational attainment. For clarity of presentation, educational attainment and age are represented graphically by median split. There was no difference in hippocampal volume according to education in the younger half of the subject pool. However, among older participants, more highly educated individuals had significantly larger hippocampi (***$p < 0.0001$). Error bars represent ±1 standard error.

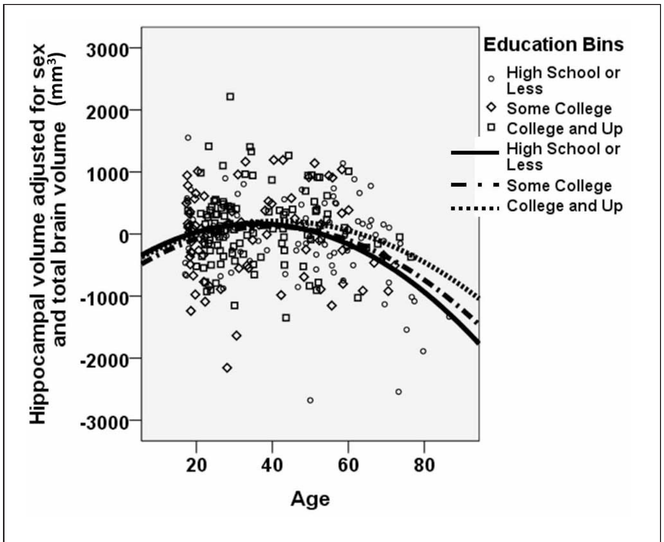

FIGURE 3 | A dose-dependent moderating effect of education on age-related decrease in hippocampal volume. A "dose-dependent" effect of education is observed. Age-related decline in hippocampal volume is most pronounced among the least educated individuals. In contrast, age-related reduction in hippocampal volume is mitigated among individuals with higher educational attainment. Hippocampal volume is portrayed as the unstandardized residual, after adjusting for sex and total brain volume. The figure excludes the 13 data points that represented "influential points" as identified using the standardized difference in beta. Note that all analyses were performed using continuous variables for age, years of educational attainment, and hippocampal volume. For clarity of presentation, educational attainment is represented graphically in bins, with high school or less portrayed with circles/solid line; some college portrayed with diamonds/dashed-dotted line; and college or beyond portrayed with squares/dotted line.

those of the 1007 participants in the full BrainNet International Database, from which our sample was drawn (Clark et al., 2006), (see **Table 3**).

On the total immediate recall score, 100% of participants in the present study performed within one standard deviation of the full sample mean. On the short delay score, 98% of participants scored within one standard deviation of the full sample mean, and 100% scored within two standard deviations. On the long delay score, 95% of participants scored within one standard deviation, and 98% scored within two standard deviations of the full sample mean. On the recognition accuracy score, 96% scored within one standard deviation, and 98% scored within two standard deviations of the full sample mean. When excluding participants who scored more than two standard deviations below the database mean on any memory subtest, the age × education interaction in hippocampal volume remained significant (Beta = 0.504; $p < 0.0004$).

DISCUSSION

Here we found that educational attainment buffers against age-related differences in hippocampal volume. Similar results were not found in the amygdala, a nearby medial temporal lobe structure, suggesting that results may be at least somewhat specific to the hippocampus.

IMPLICATIONS

The idea that, among older individuals, higher levels of education confer benefits in brain structure or function that buffer against age-related changes or brain pathology is often referred to as "brain" or "cognitive" reserve (Stern, 2002, 2006). For instance, some studies have found that Alzheimer's Disease (AD) is less prevalent among individuals with higher levels of education (Kidron et al., 1997), and it has been suggested that this may be due to a protective effect whereby individuals with more education may not manifest clinical symptoms of disease until higher levels of neural pathology are reached (Scarmeas et al., 2006; Julkunen et al., 2010; Seo et al., 2011; Liu et al., 2012).

Table 3 | Memory task performance in the present sample relative to the full database.

		Males		Females	
		Mean	**s.d.**	**Mean**	**s.d.**
Immediate recall	Present sample ($n = 114$)	32.13	4.31	33.19	4.80
	Full database	30.76	6.98	31.78	7.17
Short delay recall	Present sample ($n = 114$)	7.96	1.96	8.41	1.88
	Full database	7.52	2.62	8.04	2.60
Long delay recall	Present sample ($n = 114$)	7.41	1.93	7.90	2.17
	Full database	7.34	2.40	7.89	2.52
Recognition	Present sample ($n = 114$)	11.16	1.04	11.14	1.57
	Full database	10.96	1.40	11.06	1.30

The present study provides some support for this theory. A "dose-dependent" effect of education was found, such that age-related decreases in hippocampal volume were steepest among the least educated individuals. In contrast, age-related decrease in hippocampal volume was less pronounced among individuals with higher educational attainment. It is thus possible that, among this sample of healthy individuals, higher levels of education were able to counteract typical age-related changes in hippocampal structure. The functional significance of these differential rates of decline may reflect greater retention of the cognitive functions, including declarative memory performance, which rely on this structure (Grieve et al., 2011).

POSSIBLE MECHANISMS

Many components of SES tend to vary with educational attainment and may themselves be important factors in understanding mechanistic pathways. Other objective socioeconomic indicators include measures of income and occupation, which were not available in the dataset studied here. Although education, occupation and income tend to be highly correlated (McLoyd, 1998), they may nonetheless act independently in predicting different outcomes of interest (Duncan and Magnuson, 2012; Noble et al., 2012). For instance, previous work has suggested that family income levels and parental educational attainment may not act in concert in predicting hippocampal and amygdala volumes in children (Hanson et al., 2011; Noble et al., 2012). Further, subjective social status, or an individual's perception of where he or she stands in the social hierarchy, may predict regional brain structure and/or function over and above objective socioeconomic measures (Gianaros et al., 2007a, 2008).

Socioeconomic variables—including differences in educational attainment—likely represent relatively distal forces operating on cognitive and neural outcomes. However, SES has been associated with many factors that have been shown to exert more proximal effects on regional brain structure. One well described pathway includes differences in exposure to stress or allostatic load (McEwen, 1998, 1999, 2000, 2001a,b; Evans, 2004; Evans and Schamberg, 2009; Gianaros and Manuck, 2010; McEwen and Gianaros, 2010).

In both animals and humans, the experience of stress has been linked to differences in the structure of the hippocampus (Rao et al., 2010; Tottenham and Sheridan, 2010). The animal literature has shown cascading negative effects of early life stress on hippocampal development at the cellular, anatomic and functional levels (Sapolsky, 1996; McEwen, 1999; Brunson et al., 2005; Gianaros and Manuck, 2010; McEwen and Gianaros, 2010; Tottenham and Sheridan, 2010). Conversely, adult offspring of female rodents that exhibit high licking and grooming of pups—a model of "parental nurturance"—show increased hippocampal synaptic density and plasticity (Liu et al., 2000; Champagne et al., 2008), and improved performance in hippocampal-dependent forms of memory (Liu et al., 2000).

In studies of human adults, self-reported stress exposure, stress-related mental illness, and the prior experience of child abuse have all been associated with decreased hippocampal volume (Sheline et al., 1996; Bremner et al., 1997; Geuze et al., 2005; Kitayama et al., 2005; Gianaros et al., 2007b; Tottenham and

Sheridan, 2010; Dannlowski et al., 2012). [Findings concerning the association between stress exposure and hippocampal size in children, however, have been less consistent (Woon and Hedges, 2008; De Bellis et al., 2010; Rao et al., 2010)].

In the socioeconomically diverse sample of adults studied here, one possibility is that differences in the experience of stress may mediate the association between educational attainment and hippocampal volume. Future research will be necessary to directly test this putative mediating pathway.

Interestingly, and contrary to initial predictions, we only found a moderating effect of educational attainment on regional volume in the hippocampus, and not in the amygdala. Research in animals has demonstrated that the experience of stress profoundly affects development of the amygdala (Makino et al., 1994, 1999; Bonaz and Rivest, 1998; Wood et al., 2003; Moriceau, 2004), and human neuroimaging studies also suggest that the amygdala may be structurally altered by stress (Tottenham et al., 2010). Thus, if the reported effects of education could be completely explained by differences in exposure to stress, one would have expected to see effects in the amygdala as well. It is therefore likely that some other mechanistic factors might explain the effects of educational attainment on hippocampal volume described here. Of course, many factors, including but not limited to prenatal factors, nutrition, exercise, parenting, and the quality and quantity of the schooling experience, are associated with an individual's educational attainment, and may serve as more proximal mechanisms underlying the results reported here. Indeed, it is likely that multiple such experiential factors contribute to the moderating effects of educational attainment on hippocampal volume.

Finally, while differences in experience have direct effects on the hippocampus, it should also be noted that interactions between age, educational attainment and hippocampal volume may in part be explained by differences in genes and/or gene-environment interactions. Future research will be necessary to disentangle the various causal pathways.

EFFECTS OF EDUCATION ACROSS THE LIFESPAN

In a recent study of 60 socioeconomically diverse children and adolescents, we found that parental education levels predicted children's amygdala volumes, but not hippocampal volumes (Noble et al., 2012). (In contrast, parental income levels predicted hippocampal but not amygdala volumes.) This differs from the findings reported here, in which educational attainment moderated hippocampal, but not amygdala volume. Several notable differences may help to reconcile these findings.

The two studies included a non-overlapping age range of participants: the previous study examined children between the ages of 5 and 17, whereas the present study includes individuals between the ages of 17 and 87. Human neuroimaging studies have suggested that the effects of adversity on amygdala structure may vary based on the age of the population studied. In adulthood, the experience of highly stressful events has been associated with smaller amygdala size (Driessen et al., 2000; Schmahl et al., 2003; Tottenham and Sheridan, 2010), whereas in children, adverse caregiving circumstances have been associated with atypically large amygdala volume (Mehta et al., 2009; Tottenham et al., 2010). Thus, it is similarly possible that any effects of education on amygdala structure may be different in childhood versus adulthood, even considering the broad range of adult ages studied here.

A second possible explanation is that the previous study in children examined *parental* education levels, whereas the current study examined the *participants'* education levels. (Unfortunately parental educational attainment was not available in the current dataset.) It is therefore possible that differences in parental education may reflect differences in childhood experience or parenting that are not necessarily captured by one's own ultimate educational attainment. For instance, lower parent education has been associated with lower levels of parental nurturance (Brooks-Gunn and Markman, 2005), which may have particular importance for amygdala structure (Tottenham et al., 2010). Additionally, it is possible that the association between adult educational attainment and hippocampal volume may be mediated by the material resources individuals were exposed to as children (e.g., parental SES). Indeed, differential effects on hippocampal volumes have been described as a function of childhood SES versus adult SES. For example, several reports have found that higher childhood SES is associated with larger hippocampi (Hanson et al., 2011; Jednoróg et al., 2012; Noble et al., 2012). Intriguingly, Staff et al. (2012) recently reported that childhood SES, as operationalized by adult recall of childhood home conditions and paternal occupation, predicted adult hippocampal volume, whereas adult SES did not. This suggests that the high degree of neural plasticity in childhood may underlie effects observed decades later. Ideally, future work in adults will incorporate measures of both parental education and participant education to better sort out these disparate effects.

A third possibility is that the previous study, with only 60 participants, had reduced power with which to detect an effect of education on hippocampal volume, whereas the greater sample size in the present study allowed such an effect to be revealed here. This explanation alone would not, however, explain why we failed to find a link between educational attainment and amygdala volume in the present study.

LIMITATIONS

This study suffers from several limitations. First, by nature, it is difficult to draw strong conclusions concerning development and aging in a cross-sectional sample. While a longitudinal study spanning the entire 7-decade range of the present sample is unlikely to be feasible, longitudinal data are currently being acquired on a subset of these individuals, which may provide better evidence concerning rate of change.

Secondly, because this study represented a secondary analysis of an existing dataset, the sample was not originally recruited with the goal of optimizing educational diversity across the age spectrum. Thus, one limitation is the commonly reported negative correlation between age and education in the study participants (Piras et al., 2011). However, all analyses adjusted for age, and we attempted to mitigate such concerns in the interaction analyses by excluding overly influential points. Nonetheless, future investigations should intentionally recruit a sample in which age and education are fully de-confounded. Further, we do not have data regarding whether participants received all their education early in life, or whether they instead obtained part-time or "continuing education" later in adulthood.

Third, as mentioned above, we had no information on other aspects of objective or subjective SES, such as income, occupational status, or perceived social standing, which may have differentially predicted regional brain volumes. Nor did we have information on environmental factors, such as exposure to stressors or other putative mechanistic factors, which would have enabled us to directly test the degree to which such factors mediate our findings.

Fourth, although all participants were healthy at the time of testing, no specific screening for neurodegenerative disorders was performed, and it is therefore possible that some participants who would go on to develop neurodegenerative disease later on may have showed early signs of brain atrophy. A subset of participants had complete data on a memory recall and recognition test, and among this subset, scores were very similar to the full database of participants who completed this task, suggesting that at the time of scanning, the vast majority of participants had normal memory performance. Further, results were unchanged when known outliers on this were excluded. Nonetheless, this represents an important limitation given the increased risk of developing AD among individuals with low levels of education (Karp et al., 2004).

Finally, although the moderating effect of education on hippocampal volume across the lifespan is provocative, the direction of causality is unclear. Future work should build upon these findings by collecting longitudinal data on educational attainment, hypothesized environmental mediators, and brain structure over time.

CONCLUSIONS

Across a 7-decade age range in adulthood, higher educational attainment buffers age-related decline in hippocampal volume, such that hippocampal volume tends to markedly decrease with age among less educated individuals, whereas hippocampal volumetric decreases with age are less pronounced among more educated individuals. No such effects were found for amygdala volume. This provides some support for "brain reserve theory" and suggests the possibility that higher education may be protective against age-related regional volumetric decreases. Alternatively, it is possible that higher education may allow for better compensatory mechanisms. Future research will be necessary to elucidate the mechanisms that underlie these effects.

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High cognitive reserve is associated with a reduced age-related deficit in spatial conflict resolution

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Several studies support the existence of a specific age-related difficulty in suppressing potentially distracting information. The aim of the present study is to investigate whether spatial conflict resolution is selectively affected by aging. The way aging affects individuals could be modulated by many factors determined by the socieconomic status: we investigated whether factors such as cognitive reserve (CR) and years of education may play a compensatory role against age-related deficits in the spatial domain. A spatial Stroop task with no feature repetitions was administered to a sample of 17 non-demented older adults (69–79 years-old) and 18 younger controls (18–34 years-old) matched for gender and years of education. The two age groups were also administered with measures of intelligence and CR. The overall spatial Stroop effect did not differ according to age, neither for speed nor for accuracy. The two age groups equally showed sequential effects for congruent trials: reduced response times (RTs) if another congruent trial preceded them, and accuracy at ceiling. For incongruent trials, older adults, but not younger controls, were influenced by congruency of trial$_{n-1}$, since RTs increased with preceding congruent trials. Interestingly, such an age-related modulation negatively correlated with CR. These findings suggest that spatial conflict resolution in aging is predominantly affected by general slowing, rather than by a more specific deficit. However, a high level of CR seems to play a compensatory role for both factors.

Keywords: cognitive aging, conflict, cognitive reserve, spatial Stroop

INTRODUCTION

Everyday several kinds of information are simultaneously processed by our brain, and one of the most demanding tasks is to cope with conflicting incoming stimuli. For example, crossing an intersection when the traffic light is green does not require a high level of attention, but it is essential that our attentional system is able to increase control when needed, such as when a traffic officer is directing your car to stop despite the green light. In this second case, you must inhibit the more automatic response in favor of the non-routine action. Since avoiding critical errors by suppressing inappropriate, but prepotent responses is crucial in everyday life, conflict resolution is a widely studied aspect of selective attention.

Different aspects of conflict have been investigated, but a well-known type of conflict is the semantic one tapped in the classic color-word Stroop task. It is still a matter of debate whether there is a general system to cope with cognitive conflict, devoted to the resolution of conflict, rather than multiple domain-specific ones. In the classic color-word Stroop task, participants are required to respond to the ink color (target) of a word and to ignore the word meaning (distractor), itself referring to a color (e.g., RED written in blue). This task has been widely used in order to explore verbal conflict resolution (Stroop, 1935; Dyer, 1973; Posner and Snyder, 1975; MacLeod, 1991), whereas its spatial version has been used less frequently (e.g., Lu and Proctor, 1995; Funes et al., 2010). In the spatial version of the Stroop task, the stimulus is usually an arrow positioned in a specific position on the screen. The task consists of responding according to the direction of the arrow (target) while ignoring its position (distractor). If the distractor and the target refer to the same spatial feature, the stimulus is considered "congruent," whereas when they refer to different spatial features conflict takes place, and the stimulus is therefore called "incongruent". Conflict is usually measured as the Stroop effect, that is the performance difference between congruent (C), or conflict absent, and incongruent (I), or conflict present, trials.

Moreover, conflict sequential effects have been also reported in many different tasks, such as the color-word Stroop (e.g., Kerns et al., 2004), the Simon (Strümer et al., 2002; Wühr, 2005; Kunde and Wühr, 2006; Notebaert et al., 2006; Vallesi and Umiltà, 2009), and the flanker (Gratton et al., 1992) tasks. These sequential effects consist on the fact that the congruency of the preceding trial (trial$_{n-1}$) influences conflict resolution in the current trial (trial$_n$): the Stroop effect decreases after incongruent trials$_{n-1}$ and increases after congruent trials$_{n-1}$. This well-known pattern of conflict adaptation, also known as Gratton effect (Gratton et al., 1992; Kerns et al., 2004; West and Moore, 2005), suggested the presence of a conflict monitoring system, which includes the anterior cingulate and lateral prefrontal cortex (Botvinick et al., 2001). This system increases cognitive control whenever conflict is detected, in order to reduce the influence of distracting information. An alternative set of theories suggests that such a conflict adaptation pattern is due to priming or binding effects, rather than to a specific monitoring/resolution system. In fact, the subsequent presentation of stimuli with the same type of congruency increases the probability that one or both features constituting the stimulus would also be repeated, giving rise to negative and repetition priming (Mayr et al., 2003; Nieuwenhuis et al., 2006), or to binding (e.g., Hommel et al., 2004; Notebaert and Verguts, 2007) phenomena.

The prefrontal cortex plays an important role in conflict resolution (Botvinick et al., 2001; Mansouri et al., 2007; Floden et al., 2011), and since many cognitive aging theories assume a progressive decline of frontal brain areas (e.g., West, 1996; Braver and Barch, 2002; MacPherson et al., 2002), it is not surprising that many authors reported an age-related decrease in conflict resolution abilities, both in color Stroop tasks (e.g., West and Bell, 1997; West and Alain, 2000; Davidson et al., 2003) and in spatial Stroop or Simon tasks (Van der Lubbe and Verleger, 2002; Bialystok et al., 2004; Proctor et al., 2005; Castel et al., 2007). Indeed, West's "frontal lobe hypothesis" of cognitive aging (West, 1996) asserts that cognitive processes supported by the prefrontal cortex are more prone to age-related decline with respect to processes subtended by non-frontal regions (Dempster, 1992; Moscovitch and Winocur, 1992; Hartley, 1993; Juncos-Rabadán et al., 2008). On the other hand, since an increase of response times (RTs) is consistently found in cognitive aging studies, a general slowing theory has also been proposed (Salthouse and Babcock, 1991; Salthouse, 1996), which suggests that non-pathological aging exerts a global slowing effect on cognitive processes. It is important to note that system-wide slowing and frontal lobe-specific declines can coexist. Therefore, in aging studies it is important to clarify whether older adults show increased RTs (1), because they are generally slower with respect to younger adults, (2) because aging has a specific impact on a well-defined deficit, or (3) because there is a combination of the two.

A number of previous studies about conflict resolution in aging drew their conclusions without applying a correction for general slowing. Furthermore, to the best of our knowledge, none of them properly separated the spatial conflict resolution process from priming/binding phenomena, which, as expressed above, could be largely responsible for the observed conflict adaptation effects. The main aim of the present study is to verify whether there is an age-related deficit specific for spatial conflict resolution, after controlling for the possible confounds due to priming or binding effects. We addressed this issue by using a priming-free spatial Stroop design (at least in terms of first-order trial sequences), in order to minimise the contribution of repetition priming on conflict resolution.

Another goal of the study was to explore whether intelligence and some factors influenced by the socio-economic status, such as cognitive reserve (CR) and years of education might partially account for the age-related inter-individual variability in performance. Some studies suggest a strong relationship between intelligence and a high level of cognitive functioning in aging (e.g., Alexander et al., 1997; Albert and Teresi, 1999). We therefore used a subset of the Wechsler Adult Intelligence Scale subtests (WAIS; Wechsler, 1981) in order to assess each participant's Intelligence Quotient (IQ) and correlate it with performance measures. In the course of the last few decades, the concept of CR (Stern et al., 1994, 1995) has been used to explain why similar brain damage could lead to different levels of cognitive impairment (Katzman et al., 1989; Ince, 2001). CR has been described as a set of beneficial effects on neural plasticity and cognitive strategies derived from a lifestyle rich of experiences, such as a higher education level, occupational attainment and leisure activities (Rocca et al., 1990; Evans et al., 1993; Stern et al., 1994, 1995; Mortel et al., 1995; Manly et al., 2003; Valenzuela and Sachdev, 2006). This approach suggests that a high level of CR may be a key factor to delay the decline of cognitive functions, in as much as the use of pre-existing cognitive processes, or the development of new compensatory processes, could allow the aging brain to cope actively with loss of functionality (Stern, 2002). Indeed, many studies have suggested a compensatory role of CR against non-pathological cognitive aging (e.g., Evans et al., 1993; Stern, 2002).

Intelligence and CR might have distinct compensatory impact on cognitive functioning (Stern, 2002, 2009). Moreover, it is always necessary to be careful with data that relate intelligence and cognitive aging, since it is difficult to separate the expected beneficial effects of high IQ with respect to a possible compensation.

As Nucci et al. (2012) pointed out, intelligence definition and measurement are based on intellectual performance (Wechsler, 1944), whereas cognitive reserve is based on the concept of cognitive skills acquired during one's lifetime (e.g., Stern, 2002, 2009). Therefore, we decided to measure and treat cognitive reserve and intelligence separately. We anticipate here that the absence of a significant correlation between CR and IQ in our sample (see **Table 2**) supports our assumption.

We assessed verbal and performance intelligence with a set of WAIS subtests (Wechsler, 1981), in addition to a measure of CR (Nucci et al., 2012, see section "Materials and Methods"). Additionally, we decided to consider years of education not only as a contribution for the CR score, but also as a separate independent predictor.

To summarize, we wanted to verify whether cognitive aging specifically affects spatial conflict resolution using a priming-free experimental task, similar to the one adopted in our previous works, which were focused on verbal conflict resolution (Puccioni and Vallesi, 2012, in press). We then analyzed our data by trying to disentangle between age-related general slowing and a specific conflict resolution deficit. Furthermore, this work aimed at investigating if factors such as CR, years of education and intelligence may play a compensatory role against age-related deficits in spatial conflict resolution.

MATERIALS AND METHODS

PARTICIPANTS

Seventeen older adults (mean age = 73 years, range 69–79; 8 females) and eighteen younger controls (mean age = 24 years, range 18–34; 9 females) participated in this study. All participants were native Italian-speakers and right-handed, as measured with the Edinburgh Handedness Inventory (Oldfield, 1971). All participants had normal or corrected-to-normal vision and normal color perception, as assessed with the Ishihara Color Vision Test (Ishihara, 1962). The two age groups had attained the same years of formal education on average (younger, range: 9–18, $M = 13.4$ years; older, range: 6–18, $M = 12.5$ years, [$t_{(33)} = 0.764$, $p = 0.449$]). None of the older adults met the criteria for dementia as assessed with the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005; score range: 26–30/30). Five of them reported regular consumption of medications for cardiovascular disease. Two extra participants were excluded: an older participant because of a low MoCA score (24/30), and a younger participant because of low intelligence scores (IQ = 72). The present study was approved by the SISSA ethical committee. Each participant signed an informed consent form and received 15 € to take part in the experiment. All participants also performed a verbal Stroop task in a different session, on a different day. The results of this other study are reported elsewhere (Puccioni and Vallesi, in press).

EXPERIMENTAL MATERIAL AND DESIGN

Participants were individually tested in a dimly lit room, sitting at a distance of about 50 cm from the computer LCD monitor to perform the Stroop test. First, two single-feature tasks were administered: Direction Only, Position Only. Then participants were administered three spatial Stroop blocks. An instruction page preceded the presentation of each task.

In each condition, the stimuli were presented against a light-gray background. Participants were asked to maintain their gaze on a fixation cross shown in the middle of the screen. Four response buttons were arranged in order to reflect the north–east, north–west, south–east or south–west directions (see **Figure 1**).

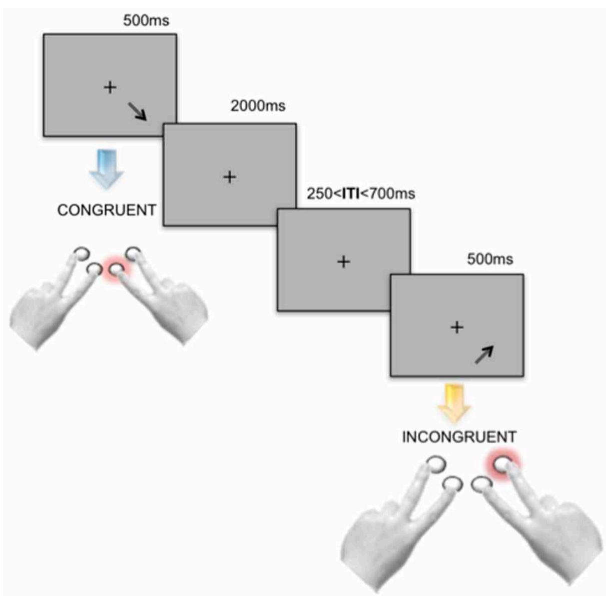

FIGURE 1 | Experimental design. During all the three experimental tasks—Direction Only, Position Only and spatial Stroop—each stimulus was presented for 500 ms, followed by a blank screen showing the fixation cross and lasting 2000 ms. Before the onset of subsequent stimulus, an Inter-Trial-Interval (ITI) varying randomly and continuously between 250 and 700 ms was presented. Stroop stimuli were divided in Congruent and Incongruent with respect to the direction of the displayed arrow and its position on the screen. Participants were asked to respond by pressing one out of four response buttons displayed as shown in the panel. In the picture two Stroop trials are represented.

Participants were asked to give a response as fast and accurately as possible by using the index and middle fingers of both hands.

In the Direction Only task, the fixation cross disappeared at stimulus onset and was replaced with one out of four different arrows (2.5 cm long × 1.5 cm wide) pointing to north–east, north–west, south–east or south–west. Participants were asked to indicate the direction of the arrow by pressing the corresponding button.

In the Position Only condition, stimuli were Xs (each arm 2.5 cm) appearing in one out of four different positions on the screen: upper right, upper left, lower right, lower left part of the screen (about 8 cm from the fixation cross). Participants were asked to indicate the position of each stimulus by pressing the corresponding button. For each of the two single-feature tasks, 32 test trials were administered, preceded by 2 training trials.

In the spatial Stroop task, one arrow out of four (pointing to north–east, north–west, south–east or south–west) appeared in one out of the four positions on the screen (upper right and left, lower right and left). Participants were required to ignore the position and to respond according to the pointing direction of the arrows by pressing the corresponding button.

The Stroop stimuli were categorized as *congruent* (e.g., north–east pointing arrow positioned in the upper right part of the screen) and *incongruent* (e.g., north–east pointing arrow positioned in the upper left part of the screen) and only complete alternation sequences were used. This implies that the position (distractor) and the direction (target) of the stimuli in trial$_n$ were always different from their position and direction in trial$_{n-1}$ (e.g., north–east arrow in the lower right part, followed by north–west arrow in the lower left part). Moreover, we categorized subsequent pairs of trials according to the congruency status of trial$_{n-1}$ and trial$_n$ as: congruent-congruent (CC), congruent-incongruent (CI), incongruent-congruent (IC), incongruent-incongruent (II). In order to familiarize with the task, participants performed a training phase at the beginning of the Stroop task, composed of 16 trials, with all possible position-direction combinations. During the training phase, each stimulus remained on the screen until a response was detected. Then feedback on accuracy and speed appeared for 1200 ms, followed by an Inter-Trial-Interval of 500 ms. The feedback was "Good" (in Italian: "Bene"), for a correct response within 2000 ms from trial onset; "Correct, but try to be faster ... " (in Italian: "Corretto, ma cerca di essere piú veloce ... ") for a correct response which occurred later than 2000 ms after stimulus onset; "Wrong" ("Sbagliato") for incorrect responses. If participants made more than 6 errors out of 16 trials during the training phase, they had to repeat this phase. This was the case for five older adults, who had to repeat twice the training phase. The test phase was divided in three blocks, each one composed of 2 sub-blocks of 64 stimuli each. Each sub-block was composed of at least 30 *congruent* trials, in order to minimize the influence of task strategies-related to unbalanced frequencies of congruency conditions (Gratton et al., 1992; see also Vallesi, 2011). Each of the four possible sequential conditions (CC, CI, II, and IC) was presented in at least 15 trials (cf., Mordkoff, 2012). In each test trial, the target stimulus appeared at the center of the screen for 500 ms, followed by a blank of 2000 ms whose offset corresponded to the response deadline (2500 ms). An extra blank screen, which lasted randomly and continuously between 250 and 700 ms, was presented before the onset of the next trial.

Nine subtests of the WAIS-R (Wechsler, 1981) were administered to the participants in order to calculate their IQs. The selected subtests were: Block Design, Arithmetic, Vocabulary, Similarities, Comprehension, Digit Span, Digit-Symbol, Object Assembly, and Picture Completion. WAIS subtests were administered during the intervals between Stroop blocks in two separate sessions (counterbalanced order) run on different days. Younger and older adults samples resulted to have a comparable IQ [younger, range: 79–120, $M = 100$; older, range: 93–109, $M = 100$, ($t_{(33)} = -0.03$, $p = 0.97$)].

In order to quantify CR, after the last Stroop block older participants only were administered the "Cognitive Reserve Index questionnaire" (CRIq; Nucci et al., 2012). To compute the CR index, the contribution of factors such as activities (sport, leisure, and cultural), years of education, and occupation, carried out by participants during their adult lifetime were weighted and combined in a composite score (Nucci et al., 2012). As Nucci et al. point out, since there are no similar standardized instruments to measure this construct for the Italian population, it is not possible to assess concurrent validity of the CRIq (Nucci et al., 2012). Although this instrument presents some limitations, such as a modest reliability (Cronbach's $\alpha = 0.62$, 95% Confidence Intervals: 0.56–0.97) (Nucci et al., 2012), we think that keeping intelligence and lifestyle-related factors separated is very interesting in order to investigate which aspect could modulate more the effect of cognitive aging. The CRI score of the sample ranged from 101 to 136, with an average score of 121 ± 11.

DATA ANALYSIS

Trials with RTs faster than 100 and slower than 1500 ms were excluded (1.97%). For each participant, trials above and below 3 *SD* from the mean RT were also excluded (1.06% of total trials). Error trials and trials following an error were not considered in the RT analysis to avoid post-error slowing confounds (Burns, 1965).

Since we were interested in exploring the possible age-related effect specifically on conflict resolution, we applied a logarithmic transformation of RT data in the analysis which was intended to compare the two age groups (see Verhaeghen et al., 2005). This transformation converts proportional effects into additive ones. We thus assume that age-related slowing to be constant across conditions, allowing subsequent ANOVAs to compare younger and older adults across conditions in the absence of group differences in speed. Hence, significant interactions that resist logarithmic transformations can be considered as due to true condition-specific effects. On the contrary, if interactions that were significant before the logarithmic transformation are not significant any more after it, it is possible to assign the effects to general factors such as age-related slowing (Salthouse and Babcock, 1991; Salthouse, 1996).

After logarithmic transformation of raw RT data, we run a $2 \times 2 \times 2$ mixed ANOVA with congruency of trial$_n$ and congruency of trial$_{n-1}$ as within-subject factors and age group as between-subjects factor. However, we used raw RTs for the analyses conducted within each group (e.g., correlations).

Since the raw accuracy data were not normally distributed, we used the accuracy Stroop effect (measured as the difference between incongruent and congruent trials), which was instead normally distributed, as a dependent variable to perform a 2×2 mixed ANOVA with congruency in trial$_{n-1}$ as the within-subjects factor and age group as the between-subjects factor. Moreover, we run a $2 \times 2 \times 2$ mixed ANOVA with congruency of trial$_n$ and congruency of trial$_{n-1}$ as within-subject factors and age group as between-subjects factor and applied a permutation test to evaluate the interaction between age groups and congruency conditions.

The Mann–Whitney *U*-test was applied, whenever the analysis intended to compare the two age groups across conditions.

In order to explore the amount of interference or facilitation that the presence of two features, either conflicting with each other or not, could produce when responding to a stimulus, we also run the same analysis considering the performance of Direction Only as baseline. Thus, after logarithmic transformation, we subtracted the RTs of Direction Only from those of the other conditions (Position Only, CC, IC, CI, II), whereas, for accuracy, we subtracted the percentage of accuracy for all conditions from that of Direction Only.

Additionally, in order to measure the amount of learning that took place across the three blocks, we run a $2 \times 2 \times 3$ ANOVA (age group $\times$ trial$_n$ congruency $\times$ block) on log-RTs, whereas, for the same kind of analysis on accuracy data, given their non-normality, we run a Two Way ANOVA (age group $\times$ block) on accuracy Stroop effect. We also conducted correlation analyses between RTs Stroop data and measures of CR, intelligence and years of education. Since these analyses were run separately for each age group, we did not use logarithmic transformations but rather raw data. Furthermore, considering that we collected CR information in the older group only, we wanted to explore the separate contribution of CR and age in the older adults. Hence an ANCOVA was run for the older group only, using age and CRI as predictors.

RESULTS

DIRECTION ONLY AND POSITION ONLY CONDITIONS

Average RTs and accuracy are reported in **Table 1**. Both younger and older adults showed a better performance in the Position Only condition with respect to the Direction Only one. RTs were indeed significantly shorter in Position Only than in Direction Only for younger ([$t_{(17)} = 5.29$, $p < 0.001$], mean RT: 403 and 447 ms, respectively) and older adults ([$t_{(16)} = 5.44$, $p < 0.001$], mean RT: 534 and 603 ms, respectively) (see **Figure 2A**). Younger adults showed also a slightly higher accuracy level in Position Only with respect to Direction Only [$t_{(17)} = 2$, $p = 0.04$], whereas this was only a tendency for older adults [$t_{(16)} = 13$, $p = 0.07$] (see **Figure 2B**). Even after logarithmic transformation of RTs, the older group was slower with respect to the younger one both for Position Only [$t_{(33)} = -5.79$, $p < 0.001$, mean RT: 534 and 403 ms, respectively] and for Direction Only [$t_{(33)} = -7.64$, $p < 0.001$, mean RT: 603 and 447 ms]. Younger and older adults showed a comparable level of general accuracy in both

Table 1 | Mean RTs and accuracy with respect to conditions and age groups.

		CC	IC	CI	II	Direction Only	Position Only
Younger	RTs	437 (49)	459 (61)	551 (84)	544 (83)	447 (48)	403 (51)
	Accuracy	99.5 (0.7)	99.7 (0.6)	92.5 (7.5)	94.7 (0.5)	98.6 (2.1)	99.4 (1.2)
Older	RTs	610 (106)	640 (113)	772 (124)	753 (120)	603 (81)	529 (86)
	Accuracy	99.1 (1.4)	99.1 (1.5)	91.0 (11.5)	94.4 (10.6)	96.5 (3.6)	98.1 (2.9)

Standard deviation in parentheses.

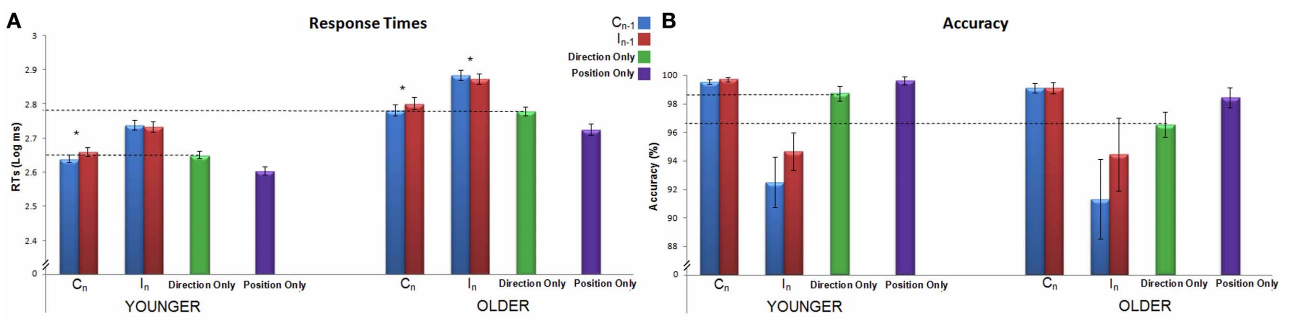

FIGURE 2 | Response times in ms (Panel A) and accuracy percentage (Panel B) of the spatial Stroop task for both age groups are shown. On the *x* axis the two spatial Stroop trial$_n$ conditions are displayed: Congruent (C) and Incongruent (I), $*p < 0.05$; in addition to the single-feature conditions: Direction Only and Position Only. The colors of the different columns refer to previous trial congruency, as shown in the legend. Dotted lines representing the average performance in Direction Only are drawn to easily compare this condition with the Stroop ones. Error bars represent the standard error of the mean.

single-feature tasks (Position Only: younger: 99%, older: 98%; Mann–Whitney $U = 119$, $Z = 1.10$, $p = 0.27$; Direction Only: younger: 98%, older: 96%; Mann–Whitney $U = 105$, $Z = 1.57$, $p = 0.12$).

SPATIAL STROOP TASK

Average RTs and accuracy are reported in **Table 1**. The group main effect on RTs was significant [$F_{(1, 33)} = 48.4$, $p < 0.001$, $\eta_p^2 = 0.59$], showing that the older group was slower than the younger one. Both the main effects of congruency of trial$_n$ (i.e., the Stroop effect) and congruency of trial$_{n-1}$ were significant [respectively, $F_{(1, 33)} = 393.7$, $p < 0.001$, $\eta_p^2 = 0.92$; and $F_{(1, 33)} = 19.7$, $p < 0.001$, $\eta_p^2 = 0.37$]. The interaction between trial$_n$ and trial$_{n-1}$ congruency was also significant [$F_{(1, 33)} = 80.4$, $p < 0.001$, $\eta_p^2 = 0.71$], showing a modulatory effect of trial$_{n-1}$ on the Stroop effect on trial$_n$ (see **Figure 2A**). A *post-hoc* Bonferroni comparison showed that both age groups responded faster to CC sequences than to IC ones ($ps < 0.001$); moreover, older adults responded faster to II sequences than to CI ones ($p < 0.05$), while younger adults did not ($p = 0.16$). The interactions involving group × trial$_n$ congruency, group × trial$_{n-1}$ congruency and the three way group × trial$_n$ congruency × trial$_{n-1}$ congruency interaction failed to reach significance (for all, $p > 0.33$).

The analysis concerning interference, considering Direction Only as the baseline, confirmed the results reported above. Both the main effects of trial$_n$ and trial$_{n-1}$ congruency were significant [$F_{(1, 33)} = 392.8$, $p < 0.001$, $\eta_p^2 = 0.92$; and $F_{(1, 33)} = 20.8$, $p < 0.001$, $\eta_p^2 = 0.39$ respectively]. The interaction between these two factors was also significant [$F_{(1, 33)} = 78.5$, $p < 0.001$, $\eta_p^2 = 0.70$]. Neither the main effect of age group [$F_{(1, 33)} = 1.1$, $p < 0.31$] nor the interaction between this factor and trial$_n$ and trial$_{n-1}$ congruency were significant ($p = 0.89$ and $p = 0.42$, respectively). Thus, independently of age, processing of CC sequences required the same time as the Direction Only condition, whereas interference increased if a congruent trial was preceded by an incongruent one (IC). On the contrary, processing of incongruent trials$_n$ implied greater interference with respect to Direction Only, and such interference was not modulated by trial$_{n-1}$ congruency.

Regarding accuracy, as specified above, the Stroop effect was used as the dependent variable. The main effect of group was not significant ($p = 0.848$), whereas the main effect of trial$_{n-1}$ congruency was significant [$F_{(1, 33)} = 8.283$, $p < 0.01$, $\eta_p^2 = 0.20$]. The interaction between age group and trial$_{n-1}$ congruency was not significant [$F_{(1, 33)} = 0.442$, $p = 0.511$], suggesting that the modulatory effect of trial$_{n-1}$ on the accuracy Stroop effect of trial$_n$ is not age-dependent. Due to its non-normal distribution, accuracy was further explored with a permuted mixed model ANOVA in order to check for the group × trial$_n$ congruency × trial$_{n-1}$ congruency interaction. Such interaction failed to reach significance ($N = 1000$ permutations, $p = 0.57$).

We repeated both these analyses considering Direction Only as the baseline: using the Stroop effect as dependent variable and the mixed model ANOVA coupled with the permutation procedure. The results were perfectly comparable to those of the analyses made using raw data. Results therefore suggest that accuracy does not differ in the two age groups and is modulated by congruency of current trial only (see **Figure 2B**).

The analysis conducted for exploring the learning rate showed that both age groups increased their speed along the three blocks [main effect of block ($F_{(2,\ 33)} = 40.6$, $p < 0.001$, $\eta^2_p = 0.55$)]. On the other hand, the interaction with age and trial$_n$ congruency was not significant (all $ps > 0.16$, suggesting a non-relevant reduction for the RT Stroop effect throughout the three blocks for both age groups.

Regarding the accuracy Stroop effect, the main effect of block was significant [$F_{(2,\ 33)} = 5.70$, $p < 0.005$, $\eta^2_p = 0.15$], whereas neither the main effect of age group nor the interaction between blocks and age group were significant [$p = 0.749$ and $p = 0.275$, respectively], supporting the presence of age-independent learning phenomena for conflict resolution in terms of accuracy.

CORRELATIONAL ANALYSIS

Table 2 summarizes bivariate correlations among variables.

In older adults, the CRI was associated with a reduction of influence of congruency in trial$_{n-1}$ on conflict resolution in trial$_n$: the greater the CRI was, the smaller the RT difference between CI and II sequences was [$r_{(15)} = -0.51$, $p = 0.036$, $r^2 = 0.26$] (see **Figure 3**).

The ANCOVA considered the RT difference between CI and II sequences as the dependent variable: this analysis revealed that a reduction of such a difference was associated with a high CRI [$F_{(1,\ 14)} = 4.91, p = 0.043, \eta^2_p = 0.26$], whereas the impact of age was not significant [$F_{(1,\ 14)} = 0.02, p = 0.879$].

Table 2 | Correlation between measures.

	Age	Education	IQ	CRI
YOUNGER				
Education	0.36			
IQ	0.35	0.31		
RTs	0.02	−0.01	−0.09	–
RT Stroop	0.10	−0.07	−0.25	–
RT CI-II	−0.46	−0.03	0.12	–
Accuracy	−0.04	−0.03	0.18	–
Accuracy Stroop	0.03	0.08	−0.22	–
Accuracy II-CI	0.31	0.25	0.20	–
Accuracy Stroop after congruent	0.13	0.14	−0.12	–
Run3–Run1 accuracy Stroop	−0.05	−0.01	−0.03	–
OLDER				
Education	−0.05			
IQ	0.05	0.59*		
CRI	−0.06	0.81**	0.30	
RTs	−0.15	−0.02	−0.26	0.03
RT Stroop	−0.42	−0.12	−0.19	−0.03
RT CI-II	0.07	−0.27	−0.20	−0.52*
Accuracy	−0.46	0.45	0.23	0.58*
Accuracy Stroop	0.41	−0.44	−0.26	−0.54*
Accuracy CI-II	−0.11	−0.37	−0.52*	−0.37
Accuracy Stroop after congruent	0.35	−0.47	−0.37	−0.56*
Run3–Run1 accuracy Stroop	−0.42	−0.45	−0.33	−0.54*

*Dashes indicate data not available. *$p < 0.05$; **$p < 0.001$.*

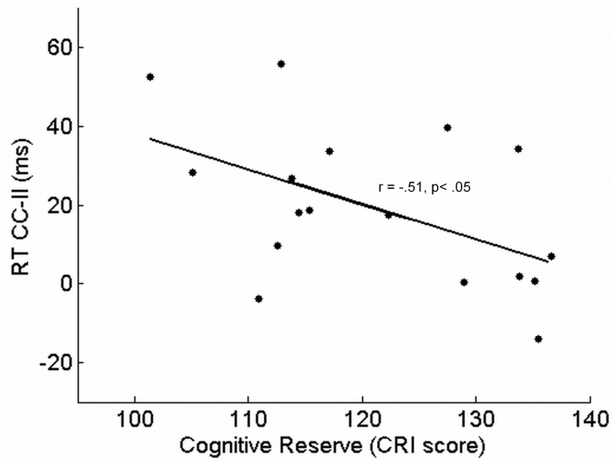

FIGURE 3 | Response times' difference between congruent-incongruent (CI) and incongruent-incongruent (II) sequences as a function of cognitive reserve, measured as Cognitive Reserve Index, in older adults.

Learning, measured as the difference between RTs Stroop effects obtained in the first and third blocks, did not correlate in either age group with either age [Younger: $r_{(16)} = -0.046$, $p = 0.857$; Older: $r_{(15)} = -0.421$, $p = 0.092$], or education [Younger: $r_{(16)} = -0.015$, $p = 0.951$; Older: $r_{(15)} = -0.453$, $p = 0.068$], although these correlations showed a trend in the older group.

DISCUSSION

This study investigated whether aging affects spatial conflict resolution and conflict adaptation, and whether CR, years of education and intelligence may play a compensatory role against age-related deficits in the spatial domain. Many studies reported age-related deficits in verbal conflict resolution, as marked by a substantial increase of verbal Stroop in older adults (e.g., Puccioni and Vallesi, in press; MacLeod, 1991; West and Alain, 2000; West and Moore, 2005), but whether aging also affects spatial conflict resolution has not been investigated as extensively. Some previous studies used spatial Stroop-like tasks with this aim (Van der Lubbe and Verleger, 2002; Bialystok et al., 2004; Proctor et al., 2005; Castel et al., 2007), and found a significant age-related increase of spatial interference. Despite the fact that many authors claimed that priming has a relevant influence in conflict resolution process (e.g., Mayr et al., 2003; Nieuwenhuis et al., 2006; Puccioni and Vallesi, 2012), none of the designs used so far to investigate aging effects on spatial conflict resolution clearly isolated priming effects from pure conflict resolution. Wühr et al., using a Simon-type task, showed the presence of correspondence sequential modulations even after a partial removal of stimulus-response repetitions (Wühr, 2005; Kunde and Wühr, 2006). However, the same authors suggested using a 4-Alternative Forced Choice (4-AFC) version of their task in order to eliminate all possible stimulus-response repetitions (Kunde and Wühr, 2006). Moreover, when investigating aging effects, it is even more important to control for priming contributions, since priming itself is likely to be differentially affected by aging (Connelly et al., 1991; McDowd and Oseas-Kreger, 1991; La Voie and Light, 1994; Mayas et al., 2012). We partially circumvented this problem by designing a spatial Stroop task that did not present stimuli with feature repetitions in any two subsequent trials. Thus, priming influences were substantially reduced. For our study, we considered the Stroop effect as a measure of spatial conflict resolution, and therefore calculated it as the difference between the performance on congruent and incongruent trials. Furthermore, we assessed the performance in two single-feature conditions, where the two features composing the stimuli used for the spatial Stroop task, namely direction and position, had to be processed separately. In all the conditions administered (Position Only, Direction Only and Spatial Stroop) older adults were systematically slower with respect to younger adults, although the accuracy level was comparable, confirming the well-known age-related slowing effect (e.g., Rabbitt, 1979; Salthouse, 1985). We confirmed that position-related information is stronger than direction-related information, since the Position Only condition was processed faster and more accurately than the Direction Only condition. In the spatial Stroop task, where both types of information are simultaneously part of the stimulus, participants were asked to respond with respect to direction and to suppress the position information. As expected, we found a significant Stroop effect for both RTs and accuracy. This priming-free spatial Stroop task revealed that older adults were slower than younger controls. Notably, the interaction between age-groups and congruency was not significant either for speed or for accuracy, indicating that the overall spatial Stroop effect did not differ in the two age groups. We also assessed the role of the preceding trial congruency, in order to investigate the influence that it could exert on the spatial Stroop effect. The two age groups equally showed the well-known sequential effects for congruent trials (Botvinick et al., 2001; West and Moore, 2005; Notebaert et al., 2006; Notebaert and Verguts, 2007): RTs were reduced if another congruent trial preceded them, although accuracy was at ceiling. For incongruent trials older adults, but not younger controls, were influenced by the congruency of the trial$_{n-1}$, increasing RTs whenever a congruent one preceded them. This pattern of results was also confirmed by the analyses run on the interference occurring in each age group with respect to its own performance in Direction Only condition. These results are in conflict with the age-related increase of spatial interference that some previous studies reported (Van der Lubbe and Verleger, 2002; Bialystok et al., 2004; Proctor et al., 2005; Castel et al., 2007). However, as we mentioned above, very few previous studies adopted experimental designs which controlled for priming or binding factors; thus they could not properly isolate the aging effects on priming with respect to those on pure conflict resolution. Moreover, some of the previous studies did not apply corrections to account for general slowing.

Despite a non-significant age-related increase of the general Stroop effect, older adults, unlike younger controls, showed an increased difficulty in incongruent trials whenever a congruent trial preceded them. Interestingly, such an age-related modulation negatively correlated with the CR index, but not with intelligence or years of education. Hence our findings suggest that the reduction of specific attention abilities that usually take place in normal aging is attenuated when individuals have a high level of CR. Future samples displaying a wider range of CRI would be useful to investigate all these associations further.

Although some studies used IQ as a measure for cognitive reserve (e.g., Alexander et al., 1997; Albert and Teresi, 1999), other evidence suggested that reserve is more deeply influenced by education and everyday life experiences. Our results support the latter findings, suggesting that intelligence, education and cognitive reserve act separately on building reserve (Rocca et al., 1990; Evans et al., 1993; Stern et al., 1994, 1995; Mortel et al., 1995). Stern's group (Scarmeas et al., 2001; Stern, 2009) reported that in a non-demented older adults' sample, individuals who were more engaged in leisure activities, both intellectual and social, had a reduced risk of developing dementia-independent of the type of activity. Moreover, leisure activities include both physical and mental exercises that have an impact not only on the pure cognitive aspects of reserve, but also on the brain structure, such as an increased brain volume (Stern, 2009). Finding an effect of CR measured with the CRIq but not of education *per se*, suggests that there is something above and beyond the education level that is related to a lower impact of cognitive aging. Therefore, a questionnaire like the one we used to measure cognitive reserve, which considers at the same time education, occupational attainment and leisure activities, seems to be a good proxy for investigating such a complex and still not sharply defined construct. Nevertheless, we think that this instrument could be further improved in the future, particularly by increasing its reliability. Furthermore, considering that participants were administered three blocks, we explored the potential learning effects that took place. Older adults obtained the same advantage as younger controls from practicing, confirming previous findings (e.g., Davidson et al., 2003): both age groups similarly increased their overall speed and the accuracy in conflict resolution (i.e., a comparable reduction of accuracy Stroop effect) over the three blocks.

The participants of the present study also took part in another study (Puccioni and Vallesi, in press), in which they were administered a matched color-word Stroop. This allows us to draw reasonable inferences about the difference that cognitive aging exerts on conflict resolution-related to two different domains: verbal and spatial. In the present study, we showed that spatial Stroop is not affected by aging, whereas the verbal Stroop effect exhibits a marked age-related increase in RTs (but not in accuracy), and roughly an opposite pattern was obtained for sequential effects (see Puccioni and Vallesi, in press). Indeed, in the verbal Stroop task, sequential effects are spared in aging. In both younger and older adults, the RT Stroop effect was nullified after preceding incongruent trials, and sequential effects relative to current congruent trials disappeared, suggesting that they are not due to conflict adaptation, but rather they are likely due to priming (or binding) phenomena. On the contrary, here we show that for the spatial Stroop switching from a congruent to an incongruent trial entails a cost in aging, and sequential effects relative to current congruent trials are present in both age groups, even after controlling for priming contribution. Therefore, our findings concerning verbal and spatial conflict resolution, when considered together, suggest the existence of two different domain-specific mechanisms responsible for conflict resolution rather than a general one. These two separate mechanisms seem to be differentially prone to cognitive aging, since verbal conflict resolution ability is specifically reduced in older adults, whereas spatial conflict resolution seems to suffer from general slowing only. Further studies, possibly with bigger sample sizes, should further test this hypothesis. Another possibility for the different results obtained in the verbal conflict resolution study with respect to the spatial one, could also be that the two tasks require different conflict resolution demands. Unfortunately, since our verbal task did not present the reading only and color naming conditions, it is impossible to directly compare the strength of the dominant condition with respect to the relevant but weaker one, and thus to make a direct comparison with the present spatial task.

It is important to point out that an experimental manipulation of intelligence and CR is not possible. Therefore, a causal relation between CR and a reduced impact of cognitive aging cannot be inferred. Therefore, to adopt longitudinal designs is extremely useful in order to understand whether CR is a reliable predictor of which individuals will be less prone to age-related cognitive decline (e.g., Snowdon et al., 1997; Stern et al., 1999; Riley et al., 2002; Wilson et al., 2002; Salthouse and Ferrer-Caja, 2003). Moreover, such an approach could also clarify if the reduced impact of cognitive aging shown by some individuals is due to a compensatory phenomenon, as suggested by the reserve hypothesis, or rather to pre-existing neural and cognitive characteristics (Nyberg et al., 2012).

In conclusion, the current study suggests that, contrary to verbal conflict resolution, spatial conflict resolution seems to be only marginally affected in healthy cognitive aging. Older adults' performance for spatial conflict resolution and spatial conflict adaptation processes is predominantly affected in terms of a reduction of the overall general speed. Older adults exhibit an age-related deficit in switching from congruent to incongruent conditions, rather than a selective impairment for spatial conflict resolution itself. Nonetheless, this deficit appears to be reduced when the cognitive reserve level is high. It could be that CR plays a compensatory role in maintaining the flexibility of active problem solving in tasks for which solutions cannot be simply derived from prior knowledge or formal education (Horn and Cattell, 1967; Stuart-Hamilton, 1996; Tranter and Koutstaal, 2008), flexibility which is usually prone to an age–related decline. Therefore, our study suggests that older adults whose lives have been characterized by a high level of cognitive reserve might cope better with some aspects of age-related attentional decline.

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