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Topical Review

Brain Imaging and Electrophysiology Biomarkers: Is There a Role in Poverty and Education Outcome Research?

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ABSTRACT

BACKGROUND: Prekindergarten educational interventions represent a popular approach to improving educational outcomes, especially in children from poor households. Children from lower socioeconomic groups are at increased risk for delays in cognitive development that are important for school success. These delays, which may stem from stress associated with poverty, often develop before kindergarten. Early interventions have been proposed, but there is a need for more information on effectiveness. By assessing socioeconomic differences in brain structure and function, we may better be able to track the neurobiologic basis underlying children's cognitive improvement. **METHODS:** We conducted a review of the neuroimaging and electrophysiology literature to evaluate what is known about differences in brain structure and function as assessed by magnetic resonance imaging and electrophysiology and evoked response potentials among children from poor and nonpoor households. **RESULTS:** Differences in lower socioeconomic groups were found in functional magnetic resonance imaging, diffusion tensor imaging, and volumetric magnetic resonance imaging as well as electroencephalography and evoked response potentials compared with higher socioeconomic groups. **CONCLUSIONS:** The findings suggest a number of neurobiologic correlates for cognitive delays in children who are poor. Given this, we speculate that magnetic resonance imaging and electrophysiology parameters might be useful as biomarkers, after more research, for establishing the effectiveness of specific prekindergarten educational interventions. At the very least, we suggest that to level the playing field in educational outcomes, it may be helpful to foster communication and collaboration among all professionals involved in the care and education of children.

Keywords: brain imaging, electrophysiology, biomarkers, poverty, education

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Introduction

In the United States, there has been great interest in prekindergarten and early childhood education to level the educational and developmental playing field across all socioeconomic status (SES) strata. Increasingly, many cities and states are prioritizing early childhood programs and interventions.[1]

The evidence concerning developmental disparities among socioeconomically disadvantaged children has evolved over the past decade, and it is now clear that children who are poor are more likely to score lower on tests of language, memory, and executive function, as well as to exhibit increased aggressive behavior, relative to higher SES children.[2,3] These disparities develop early in childhood—possibly as early as infancy.[4] In one study of kindergarten children, children who were poor tested a full standard deviation below middle class children on certain

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cognitive measures.[5,6] Good language skills and executive functions are integral to successful educational performance,[6-8] and delays in these cognitive parameters may lead to academic underachievement in general.

The mechanisms by which SES impacts early brain development are unclear but, in part, may be secondary to increased stress produced by poverty seen in early childhood.[9] Other factors could include prenatal conditions, parent-child interactions, and fewer cognitively stimulating materials in the home, such as books or educational toys.[2,9] A rodent model suggested that mice that are stressed in childhood might perform less well on cognitive tasks as adults.[10] There was an associated hippocampus atrophy in adult mice that were stressed in childhood.[10] Research in both animals and humans suggests that stressful experiences may be associated with reductions in hippocampus size.[11] Evidence suggests that these hippocampal abnormalities are likely related to activation of corticotropin hormone receptors by increasing hormone production and leading to a dysregulation of stress physiology.[11] In the rodent model, blocking the corticotropin activation ameliorates the hippocampal changes.[10]

Here we review the literature on SES disparities in brain development to evaluate what is known about differences in brain structure and function as assessed by magnetic resonance imaging (MRI) and electrophysiology and evoked response potentials (ERPs) among children from poor and nonpoor households. With the premise of a neurobiologic component to SES disparities, we focus on the potential use of MRI and electroencephalography (EEG) and/or ERPs as biomarkers for educational studies and suggest the need for increased collaboration between the medical and educational communities. This is the first review with this focus.

Materials and methods

We explored the relationship between SES (defined as parental income and/or education and/or occupation) and brain MRI and EEG and/or ERPs in the context of schooling. We conducted a literature search for English-language articles using PubMed, EBSCO, Cochrane Library, and Google Scholar. A Boolean search used the following terms: “SES,” “socioeconomic,” “ERP,” “EEG,” “school,” “education,” “kindergarten,” “MRI,” “imaging,” “brain,” and “neuroanatomy.” We extracted papers that had these keywords in full text and included any cognitive and behavioral correlates to neuroimaging, ERPs, and SES. We included studies limited mostly to children, adolescents, or adults who in childhood were from lower SES. Articles that did not use parental SES but instead used the individuals’ own educational attainment or other markers of individual SES were excluded. References within the articles were also scanned for relevant sources and articles.

Results

We found 17 papers that mentioned imaging techniques, cognition, and SES and had primary imaging data performed in childhood or in adults who had low SES as children (Table 1).[7,12-27] An additional six papers studied EEG and/or ERPs and correlations with SES (Table 2).[4,28-32]

SES differences were found in routine MRI measuring volumes of brain structures as well as diffusion tensor imaging (DTI), functional magnetic resonance imaging (fMRI) using blood oxygen level dependent (BOLD), and EEG and/or ERPs.

Functional MRI

Three studies have used neuroimaging to examine SES disparities in reading ability. In one fMRI study conducted in children at risk for reading impairment, the correlation between phonological awareness and BOLD activation during a reading task varied as a function of SES in children with the same phonological skills.[7] Specifically, among children who struggled with reading in the context of a lower SES environment, phonological awareness was a positive predictor of left fusiform activation during reading (i.e., a typical brain-behavior relationship). In contrast, among children who struggled with reading despite the resources of a higher SES environment, phonological awareness did not predict left fusiform activation during reading (i.e., an atypical brain-behavior relationship in this group). In an fMRI study of 70 adult subjects from diverse SES in childhood who had been struggling readers and who either became better readers as adults or remained struggling readers, low SES struggling readers were again showing typical brain-behavior relationships.[12] Higher SES individuals showed evidence of neural compensation (other areas were activated during reading, more than in lower SES struggling readers who improved).[12] Raizada et al.[13] showed that higher SES was associated with greater recruitment of the left inferior frontal gyrus in young children during a rhyming task, relative to right-sided inferior frontal gyrus recruitment.

Four studies have used neuroimaging to investigate other neural systems, including the limbic and prefrontal cortices. In one study of 33 adults, there was greater amygdala reactivity to threatening faces in adults who lived in low SES families as children.[14] Similarly, Kim et al.[15] studied adults who had low income-to-needs ratios at age 9 years; these adults had lower prefrontal activation and also had an inability to suppress amygdala activation with a stressor. Sheridan et al.[16,17] reported that prefrontal activation was decreased in children from lower SES families during a stimulus-response mapping task in one paper and, in another, found that hippocampal activation was decreased during a declarative memory task in children from lower SES families.

MRI (structural)

Five structural MRI studies have shown some association between hippocampal structure and SES. In a study of 23 children that assessed volumetric differences in regional brain volumes, lower SES was associated with smaller gray matter volumes in the hippocampus, as well as middle temporal gyrus, fusiform gyrus, and right inferior occipitotemporal gyrus; SES was not associated with white matter volumes.[18] SES differences in the volume of both the hippocampus and amygdala were found in another study with 60 children.[19] An investigation with 317 children showed decreases in a measure of hippocampal density with lower SES.[20] A study of 145 children showed family income-to-needs ratio correlated with total white and gray