Rich Man, Poor Man: Socioeconomic Adversity and Brain Development

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Illustration by William B Hogan

Editor's Note: Here's a disturbing statistic that made headlines this past January: The richest 85 people in the world now hold as much wealth as the poorest half. Keeping in mind the goal of closing the ever-widening gap between the haves and the have-nots, our author examines new research that ties family income level and other factors to brain development. While socioeconomic adversity may not solely determine a child's success later in life, its significant role in helping children develop language, memory, and life skills can no longer be ignored.

The human brain has been called "the most complex three pounds in the universe."[1] Indeed, this characterization does not seem hyperbolic when we consider that we are born with 100 billion neurons at birth,[2] and that an additional 250,000 to 500,000 new neurons are formed every minute in the first few months of an infant's life.[3] Further, it is not just the number of neurons, but the number of synapses, or connections *between* neurons, that is extraordinary. Synaptic connections become increasingly complex in the first few years of life, and children have 1,000 trillion connections by age three.[4] Early experiences are critical in shaping this process. In the brain, neural circuits that are used repeatedly tend to strengthen, whereas those that are not used are dropped, or pruned. The most vigorous growth and pruning of these connections occur in the first three to four years of life,[5] meaning that the brain is most plastic, or able to make new connections, early in childhood.

For example, studies in the late 1990s revealed that children who learn a second language early (prior to age seven) show neural organization of the second language that is remarkably similar to that of the first language. In contrast, among late learners of a second language, the second language is in effect "stored separately,"[6] which helps to account for poorer pronunciation and grammar in late-second-language learners.

More recently, the effects of early life experience have been applied to the study of the aging brain. As we get older, the function of our nervous system declines. For example, older adults often have difficulty understanding speech as well as their younger counterparts. This difference is particularly salient in environments with substantial background noise, such as cocktail parties. Researchers recently showed that several years of music training early in life can offset this process of auditory decline.[7] Specifically, a moderate amount of musical training in early childhood is associated with faster neural response to speech later in life, decades after the individual last picked up a musical instrument. The research suggests that early experience with music trains the brain to interact more dynamically with sound throughout a person's life.

While early exposure to additional languages or music may lead to beneficial changes in brain development, early adversity can likewise have important but detrimental effects on the brain.

Early Adversity

Children under 18 years of age represent 23 percent of the population, but they comprise 34 percent of all people in poverty. More than one in five children in the United States live in poverty, representing more than 16 million children.[8] Importantly, the definition of poverty is strictly based on family income and the number of adults and children in the home, with no adjustment for geographic location. Thus, based on the most recent federal guidelines, a family with two adults and two children is considered to live below the poverty line if they earn less than $23,550 per year, regardless of where they reside. The guidelines fail to take into account the fact that raising a family in a city like New York or San Francisco is much more expensive than, for instance, raising a family in rural South Dakota.

For that reason, many researchers partly consider the role of multiple socioeconomic factors in addition to income. Socioeconomic status, or SES, incorporates additional objective measures such as parental education and occupation. Sometimes researchers also consider subjective social status, which is an individual's subjective rating of his or her position in the social hierarchy.

Across these different socioeconomic indices, researchers have described marked disparities in a range of important cognitive and achievement measures for children, such as IQ, literacy, achievement tests, and high school graduation rates.[9] Disparities in achievement tend to emerge early and then widen throughout the early elementary school years. For example, by 10 years of age, family SES is an excellent predictor of a child's cognitive abilities: children from higher-SES families tend to perform well above children from lower-SES families—regardless of whether those children had high or low cognitive abilities at age two.[10]

Numerous factors contribute to these SES gaps in cognitive development: nutrition, environmental toxins, home learning environment, exposure to stress, and early schooling. Further, these different pathways are often highly correlated, in that disadvantaged families are more likely to be exposed to multiple risk factors than are advantaged families. As such, researchers find it daunting to tease out the mechanisms behind the SES gap in cognitive development and, in turn, to design effective interventions.

Weighing Other Factors

One way to begin to make sense of the tangled web of inter-correlated mechanisms leading to socioeconomic disparities in cognitive development is to recognize that cognitive development is itself a very broad construct—too broad to be realistically considered as a single outcome. We are therefore better off trying to understand the links between SES and *specific* aspects of cognition.

The field of cognitive neuroscience teaches us that different brain structures and circuits support distinct kinds of cognitive skills. While classic academic milestones such as school graduation can tell us broadly about global effects of socioeconomic disparities on achievement, we know that achievement is actually a complex output of multiple cognitive and socio-emotional systems, such as language, learning and memory, and self-regulation. These distinct cognitive systems are supported by different brain regions and networks. So, while classic measures of academic achievement such as high school graduation must at some level reflect the function of the brain, they are relatively uninformative when it comes to disruptions or disturbances in specific cognitive and neural processes. By taking a cognitive neuroscience approach, we may improve our efforts at providing targeted educational interventions.

This was the approach that my colleagues and I have taken, beginning when I was a graduate student with Martha Farah at the University of Pennsylvania, in a series of studies over the last decade.[11-13] In these studies, we investigated which core cognitive functions were most strongly related to SES. To do so, we recruited children from socioeconomically diverse families and administered a series of cognitive tests designed to tap in to the core

systems of language, executive function, visuospatial skills, and memory—systems that are supported by relatively distinct brain circuits. Across studies, children ranged from kindergarten through middle school age. At any one age, of course, some children perform dramatically better than others. We set out to determine the extent to which such disparities in performance could be explained by differences in SES.

The answer, it turned out, was "to a large extent." In general, children from higher SES homes tended to perform better on most cognitive skills than children from lower SES homes. However, the disparities were not uniform. Across studies, we found the largest SES disparities in language skills, with more modest differences in children's memory and executive-function abilities. For example, in one study, for each standard deviation increase in SES (operationalized as a composite of parental education, occupation, and income), language improved by more than half a standard deviation, declarative memory skill increased by approximately one-third of a standard deviation, and certain executive-function skills increased by approximately one-quarter of a standard deviation.[11] Similar socioeconomic gradients in these skills have been reported in children in developing countries.[14] More recent work from our lab has suggested that socioeconomic disparities in neurocognitive development emerge very early, with large differences in language and memory development evident before two years of age.[15]

Building on the Findings

Scientists leading other recent investigations of socioeconomic differences in brain structure and function have considered more specific cognitive and neural outcomes, and it has become possible to begin to tease apart the modifiable environmental factors that mediate these links.

Since the greatest socioeconomic disparities are present in language skills, let us turn first to several findings concerning SES disparities in the function and structure of language-supporting regions of the brain. Polish neuroscientist Przemyslaw Tomalski and colleagues recently used electroencephalography (EEG) to examine SES differences in infants' brain function.[16] This technique is widely used by investigators to examine how powerful a child's brain waves are in different locations across the scalp, thus providing some insight

into the activity in different brain regions. Their study found that by six months of age, parent occupation and income were already associated with higher-power brain waves in frontal brain regions. Critically, higher-power brain waves in these regions have been associated with better language development at later ages.[17, 18] Thus, it is possible that at least one neural signature of growing up in socioeconomic disadvantage may be detectable very early in infancy, well before behavioral measures of discrepancies in cognitive processing may be evident.

In a recent study in our lab, we examined brain volumes in a group of 60 socioeconomically diverse children ranging from 5 to 17 years of age. We found that, as children get older, higher SES children tend to dedicate relatively more neural real estate to areas of the brain that support language development, in comparison to their lower SES peers.[19] This suggested to us that something about the experience of growing up in a higher SES environment likely leads to a greater investment in language-related regions of the brain.

Indeed, this something is almost certainly experience with language itself. It is well established that children from disadvantaged homes tend to hear fewer words—an estimated 30 million fewer words by age three than their higher-SES counterparts, to be precise.[20] Lower-SES mothers are also more likely to speak to their children in a directive rather than conversational manner, and to use less complex speech patterns and fewer gestures.[20-22] It is likely that differences in maternal speech input result in a cascade of effects that are directly relevant for the development of a child's language-supporting cortex during infancy.[21] Much as greater exposure to music may increase an individual's perception of speech years later, greater social engagement with interactive adults may lead children to have improved abilities to perceive and discriminate among speech sounds.[22] Thus, one mechanistic pathway would suggest that socioeconomic disparities result in large differences in quality and quantity of linguistic exposure, which in turn lead to differences in the development of language-supporting brain regions—and, finally, to the often-reported SES disparities in children's language skills.[19]

The Role of the Hippocampus

As described above, SES disparities in children's learning and memory abilities have been also reported, independent of disparities in language. The hippocampus is one brain structure that is critical for memory development, and a number of recent studies have indicated that SES factors are associated with hippocampal size in both children[19, 23, 24] and adults across the life span.[25, 26] Research in both animals and humans suggests that the experiences of stress and neglectful or abusive parents have direct effects on the development of the hippocampus.[27-30] While family stress is certainly not limited to lower SES families, it is often disproportionately felt in more disadvantaged homes. Thus, a second pathway would suggest that SES differences in exposure to stress may operate on the hippocampus to mediate previously described SES disparities in declarative memory processes.[19] Supporting this notion, Joan Luby of Washington University-St. Louis and colleagues recently found that more hostile parenting relationships and family stress accounted for links between income and hippocampal size.

Finally, socioeconomic disadvantage is associated with a decreased ability to regulate cognition[11-13, 31] and emotions,[32-34] a critical aspect of school readiness that predicts grades and achievement-test scores from elementary through high school. Recent work from a number of laboratories has demonstrated SES disparities in the neuroanatomic structure and function of the prefrontal and limbic cortical regions that support these skills. [19, 35-40] Again, chronic stress has been associated with alterations in the development of this circuitry. [29, 41] Thus, a third pathway would suggest that SES differences in exposure to stress may also operate on prefrontal cortex and limbic circuitry, thus mediating previously described SES disparities in self-regulation.[19] For example, NYU developmental psychologist Clancy Blair and colleagues[42] reported that the link between positive parenting behaviors and children's executive function was partially mediated through the stress hormone cortisol, and Nim Tottenham of Columbia University recently showed that early adversity in the form of maternal deprivation leads to premature adult-like connections between prefrontal and limbic regions.[41]

Thus, mounting evidence suggests that socioeconomic factors—parental education or family income—may lead to differences in the home-language environment or exposure to

family stress, which in turn have cascading effects on the development of brain systems that support critical neurocognitive functions such as language, memory, and self-regulation. And yet we still do not know the level at which it is most efficacious to intervene.

Closing the Gap

Are our efforts best directed at improving disadvantaged children's educational experiences, with a focus on language, memory, and self-regulation skills? School-based interventions are certainly the most prevalent form of early-childhood intervention, and many, such as the Chicago School Readiness Project[43] and Boston's pre-K program,[44] have shown promising gains in both preacademic and self-regulatory skills for disadvantaged children. And yet, while these programs can be effective, they are unlikely to be sufficient: Given the size of the SES gap by the time children enter school, preschool interventions alone are unlikely to bridge the gap fully.[45] Some small, intensive early childhood programs such as Perry Preschool or Abecedarian have been shown to result in substantial long-term benefits on cognitive development and achievement, and even physical health as children enter adulthood.[46, 47] However, the pragmatics of scaling up such programs to the larger population while maintaining high quality is a frequently cited concern.

Young children spend the vast majority of their time with their parents and other caretakers, and so perhaps we should we be focusing on parents' behaviors. Highly educated parents invest far more time playing with, talking to, and teaching their children, and parenting style has been cited as the single most important factor in explaining the SES gap in cognitive development.[48] And so, perhaps targeting parenting would be the most effective avenue of intervention. Small-scale interventional efforts to teach disadvantaged parents about the benefits of speaking early, often, and richly to their children are producing promising results.[49] However, while some larger-scale parenting interventions such as the Nurse-Family Partnership program have led to moderate improvements in children's cognitive and behavioral outcomes, [50] many have a mixed record of success,[51] often due to difficulties with attrition and low participation. Overcoming obstacles to scaling up such interventions will require researchers and policy makers to carefully consider parental motivations and beliefs.[45]

Finally, let us consider interventions that operate at the most distal level—that of SES itself. Correlational evidence suggests that, for disadvantaged families, a $4,000 increase in family earnings in the first two years of a child's life leads to remarkable differences in that child's adult circumstances, including a 19 percent increase in adult earnings, a marked increase in hours spent in the workforce, and even some evidence of improved physical health in adulthood.[52, 53] While family income alone is unlikely to be the most important factor in setting young children along an achievement trajectory, it may well be the most malleable factor from a policy perspective. Thus, based on the evidence described above, many leading social scientists and neuroscientists believe that policies that reduce family poverty would have meaningful effects on early caregiving and reductions in family stress, ultimately improving children's brain functioning and promoting the cognitive and socio-emotional development that is so critical for children to succeed and to lead healthy, productive lives.

Bio

Kimberly Noble, M.D., Ph.D., is an assistant professor of pediatrics at Columbia University, where she studies socioeconomic disparities in children's neurocognitive development. Trained as a developmental cognitive neuroscientist and pediatrician, she received her Ph.D. in neuroscience and her medical degree from the University of Pennsylvania. Current research interests include the time course with which socioeconomic disparities in neurocognition emerge in early childhood; the modifiable environmental factors that mediate such disparities; and the brain-behavior relationships that account for these links. Additionally, Noble is involved in several studies of interventions, including a program targeting children's literacy, math and self-regulation skills, as well as a study of the effects of experimental poverty reduction on cognitive and brain development. Noble was recently named an Association for Psychological Science "Rising Star."

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