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Poverty's Effect on the Amygdala and the Prefrontal Cortex

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ABSTRACT: Growing up in poverty can cause divergence in the amygdala and the prefrontal cortex development, especially when there is no shielding to buffer its effects. Adolescents who live or have lived in poverty and have experienced economic strife often deal with chronic stress that alters the brain's structure and functioning. The medium of stress can affect the connectivity of the amygdala and PFC, which impairs the ability to perceive and react to stress appropriately. A correlation exists between a heightened sensitivity to harmful stimuli and increased brain activity when exposed to stressors in individuals who grew up in poverty compared to their higher socioeconomic status counterparts. Many are more likely to have mental health problems and comparably diminished academic and professional abilities. Most findings point to poverty having a correlation with negative impacts on the brain in the long run, yet buffers such as suitable parenting styles can alleviate these effects. Research on poverty's impact on the amygdala-PFC connection has predominantly been conducted in Western countries and mainly the US; hence, the findings cannot be assumed to translate to other countries with different social and political climates.
KEYWORDS: Behavioral and social sciences; neuroscience; poverty; lower socioeconomic status; amygdala; prefrontal cortex; amygdala-prefrontal cortex connection.

Introduction

The foundations of the brain are fabricated in early childhood. Though the brain is in a constant state of growth, it is molded as a child grows up, and any significant changes generally cease to occur after early adulthood. Brain formation commences soon after conception, and it's governed by genetics and a range of environmental factors such as nutrition, maternal stress levels, and substance use.[1] However, the environment plays a more significant role immediately after birth. The brain develops in response to specific environmental concerns, and poverty is more correlated with experiences that tend to be classified as harmful, such as violence exposure. Thus, individuals who grew up in an environment of poverty are more likely to be impacted by the medium of 'toxic stress' on the brain. Still, it is pertinent to be aware that poverty is not necessarily bad and does not have predetermined bad outcomes on the brain.[2] This paper will focus on the amygdala, the prefrontal cortex (PFC), and the connectivity between the two and examine how these brain structures can be impacted by poverty.

Discussion

The amygdala:

The amygdala comprises a collection of nuclei found within the temporal lobe. There are two amygdalae found in both hemispheres. The most prominent nucleus has an almond-like shape, which brought about the name 'amygdala', meaning 'almond'. The amygdala is part of the limbic system, a system within the brain mainly responsible for emotional and behavioral responses, primarily centered around survival.[3] The field has shifted to thinking about the amygdala and other regions in the limbic system as a system that supports salience detection and emotion processes. Due to fear being a good indicator of danger in the environment, fearful faces activate neurons in the amygdala. Unpredictable and ambiguous stimuli are perhaps even better predictors for amygdala activation, which illustrates that the amygdala is more concerned with the salience of the stimuli for communicating something about environmental conditions. Moreover, it also processes positive stimuli and consolidates memories with strong emotional associations.[4] The full extent and understanding of the amygdala's functions have not been fully uncovered, but research also points to its role in expressing strong emotions.

The prefrontal cortex (PFC):

The PFC refers to the large area in the very front part of the brain that acts as the brain's control center. Believed to be the most advanced brain region, it undertakes the highest-order cognitive abilities. It is widely connected to other brain areas to regulate thoughts, actions, and emotions.[5] While maintaining extensive capabilities, it is primarily involved with executive functions, such as planning, decision-making, problem-solving, and social cognition.[6]

Amygdala-PFC connectivity:

Both the PFC and the amygdala have substantial neural circuits connecting them to other parts of the brain. The bidirectional connections between the PFC and the amygdala permit the overseeing of acquisition, consolidation, retrieval of fear memory, and the elimination of fear.[7] The amygdala receives negative stimuli that can be perceived as a threat, and this activates the PFC to respond to the threat in an appropriate behavioral manner.[7] The human stress response largely depends on the connection between these two structures. Any fault with the connection can cause the individual to have a diminished ability to regulate fear or stress.[8]

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Fear and stress responses:

Fear is an evolutionary behavioral response fundamental for survival, yet an inability to suitably respond to fear has copious negative consequences. There are two separate stress response systems to counter fearful or stressful stimuli: the sympathetic adrenal medullary system (SAM), commonly referred to as fight or flight, and the hypothalamic-pituitary-adrenocortical system (HPA). The HPA system supports the production and release of glucocorticoids (cortisol) and is comparatively slow to achieve full effects at 20-40 minutes. Meanwhile, the SAM system, fight or flight, activates the sympathetic nervous system and is instantaneous. Adrenaline hormones are released by the adrenal gland, which momentarily causes an increase in heart rate and blood pressure, a redirection of blood towards vital organs, paused digestion, altered memory processing, etc. The symptoms of an acute stress response ease up entirely after 20-30 minutes and have no effects beyond that.[9]

However, continuous or repeated exposure to fear or stress stimuli causes a prolonged stress response.[7] Physiologically, someone with chronic stress is more likely to experience various adverse effects, such as increased blood pressure, an increased risk of heart disease, and digestive issues.[8] To elucidate this idea, Dr. Nadine Burke Harris came up with the analogy of a bear. Usually, if someone stumbles upon a bear in the woods, their flight or fight mode would be activated. The brain would push everything aside to get to safety. The physiological effects of the fight or flight response, such as increased heart rate and blood pressure, would allow the person to escape and save their life. However, if you were to live with the bear, i.e., a person who continuously causes you to feel fear, this fear response would be constantly activated.[8] This idea transfers to people living in poverty, who may live with heightened stress. A study by UC Davis in 2021 indicated that teens living in poverty experience stronger physical signs of stress than those who are economically secure growing up. In a longitudinal study, where the research group's hair and saliva were taken to examine cortisol levels, it was found that the general stress levels were higher in those who, at a point, experienced poverty. Cortisol, the primary hormone released by the body to combat stress-inducing stimuli, was, on average, higher when the individual reported having lived in lower SES conditions. Yet, in reaction to stressful circumstances, those from a lower SES background had blunted responses to stimuli designed to be stress-inducing. Their cortisol levels rose less in comparison to their economically secure counterparts. This dulled reaction indicates the body is overwhelmed and cannot fully answer the immediate situation. As the head of the project, Lisa Johnson, said, 'This can lead to deficits in both physical and mental health'.[10]

Poverty's influence on the amygdala and PFC:

Poverty and low SES are not inherently bad and do not necessarily lead to adverse outcomes mediated by the brain.[11] The negative consequences that have been noted are not predetermined. Still, the differences between growing up in low- and high-SES environments are nevertheless significant and should be paid attention to.

Compared to children growing up in higher socioeconomic status (SES) households, children from low SES neighborhoods are more likely to develop a smaller amygdala and PFC.[12] Childhood adversity, such as poverty, has been linked with a decrease in amygdala volume but an increase in its reactivity; a smaller PFC volume; and decreased communication between the two areas. The smaller amygdala volume suggests a reduced ability to regulate fear response, while the increased activity implies that the brain perceives more threatening stimuli. A smaller PFC volume suggests a diminished capacity to respond to perceived threats and make decisions about them. A decrease in the mass and communication of both structures is found to be associated with the inability to perceive or cope with fear in an appropriate manner. Difficulty reacting to fear has wide-ranging implications in everyday life: it can lead to heightened anxiety, chronic stress, issues with decision-making, strains on interpersonal relationships, and interference with academic or professional performance.[13]

The PFC, while considered to be the most evolved part of the brain, appears to be the most sensitive to stress exposure.[5] Stress has been noted to have detrimental effects on cognition for ages. The first studies occurred after World War II when established and adept pilots continuously crashed their planes during wartime stress due to mental errors.[14] Stress of any type, even acute, can cause diminished activation of the PFC. In studies where participants were made to speak publicly or watch a sad movie, fMRI showed decreased activation in the PFC regions.[15] Most remarkably, studies have identified a sense of control as the key factor in determining the impact of stress on cognitive ability. When subjects felt in control of the stress-inducing stimuli, even if it was an illusion, they could retain their cognitive abilities, while those who felt out of control didn't.[5] Therefore, poverty, which acts through the medium of stress, can impact the cognitive abilities of those living there. People who face extreme poverty and are unable to provide necessities for themselves or their families can be susceptible to experiencing a loss of control. Hence, the stress they are potentially living under subsides PFC activity and could weaken their ability to make decisions, perform professionally or academically, and form working memories.[5]

Further, one study examining a sample of 389 people ages 4 to 22 found that families who identified themselves as in lower economic status regions correlated with reduced grey matter volumes in the PFC. Children from families at 150% of the poverty line were noted to have an average of 3-4% reductions in the grey matter volume of their PFC compared to their higher SES classmates. At 100% or below, their grey matter volume had reduced by about 8-9 % from developmental norms.[16] Hence, the study signified a link between higher levels of poverty leading to reductions in the grey matter volume of the PFC.

The effects of poverty have been noted to begin in early infancy for some individuals.[3] In an analysis of 77 children below the age of 4, the grey matter volume of those from low-income families was half a standard deviation smaller than their counterparts from high-income families. The differences were most notable in the prefrontal region of the brain.[15] The findings corroborated another study focused on the brains of infants from higher and lower SES families. An EEG, which measures the amount of brain activity, was utilized on 6-9-month-old children, and the results showed reduced high-frequency electrical oscillations from the PFC in the children from lower SES families.[12] Thus, the findings reveal a consistent association between poverty and a reduced ability for the PFC to function. The differences are thought to be developmental and could increase with prolonged exposure to poverty.

The potential effects of childhood adversity on amygdala volume remain unclear, but increases in the amygdala's reactivity have been noted. Some studies suggest that very early childhood adversity might decrease the amygdala volume, while later adversities could increase its size.[1] However, studies on the amygdala's reactivity maintain the same message. Adults with a lower SES childhood tend to have higher amygdala activity in response to fearful faces. In contrast, those with a higher SES childhood had higher amygdala activity upon seeing happy faces. The increased salience of fearful faces in those who've lived in poverty could reflect an adaptation to be more aware of dangerous and negative aspects of one's environment. Those who grew up in a lower SES environment were also more likely to view neutral stimuli as negative, which could increase the chance of experiencing depression.[18]

In a study by Park *et al*. 2018, 108 participants aged 4-7 were imaged using fMRI to compare their amygdala-PFC connectivity. The participants' families were asked to complete questionnaires to deduce the stress levels each participant experienced in their early life. The questions concerned their household's total income, the maternal level of education, and potentially traumatic experiences. The results correlated with weaker amygdala-PFC connectivity in participants with greater exposure to stressful events. Greater exposure to stressful events was more related to lower family income than the other recorded factors. Age or gender were found to not correlate with the amygdala-PFC connection.[16] A weakened connectivity conveys inefficient communication between the amygdala and the PFC and, thus, a higher risk of emotional dysregulation and mood disorders.[18]

Another study by Javanbakht *et al*. 2015, investigating responses to positive and negative faces, found a link between PFC-amygdala connectivity and SES during childhood. An inverse relationship was found between PFC activity and lower childhood income when given fearful faces to react to.[19] The PFC worked harder to regulate the amygdala's activity in response to fearful stimuli. This is attributed to a diminished efficiency in the link between the amygdala and the PFC. Both structures' activities tended to be higher in individuals from lower SES backgrounds, which was attributed to both regions needing to work harder individually to respond to perceived threats. Individuals from higher SES backgrounds had lower activity in the amygdala and the PFC and, thus, higher connection rates between the two.[4] Hence, it can be deduced that individuals from lower SES environments are more likely to use more energy to maintain regular function than people from higher SES backgrounds.

A more prominent division between the PFC and the amygdala has been linked to increased mental health problems such as anxiety or more aggressive behavior.[12] Mental health problems are more likely to develop in people who've experienced childhood adversity. Those who suffer from disorders such as anxiety have been noted to have a higher chance of irregularities in the connectivity of the amygdala and the PFC than those who do not suffer from mental disorders. A possible link exists between developing a mental health problem later in adulthood when the brain is affected by poverty or other adverse childhood experiences. Moreover, a weaker amygdala-PFC connection was associated with more aggressive behavior and attention problems in childhood. Those symptoms are often considered indicators of future adult psychopathology.[1]

Chronic stress has generally been identified as the intermediary between poverty and brain development, so the link between stress hormones and amygdala-PFC connectivity was investigated. A study published in 2021 by Tian *et al*. examined the relationship between the amygdala-prefrontal circuitry, SES, and stress hormones. The investigation examined the cortisol secretion in 239 children aged 6-12 from different socioeconomic backgrounds. It was found that lower SES children exhibited lower cortisol secretion, which mediated amygdala functional connectivity with the PFC. The lower cortisol production prompted higher amygdala activity when responding to fearful stimuli.[12] The PFC went into overdrive to combat this response, resulting in decreased connectivity between the regions. The lower cortisol secretion in response to fearful stimuli in children of lower SES backgrounds occurs due to living in a general state of stress, which weakens their responsiveness to stress-inducing stimuli compared to higher SES children. Higher levels of cortisol correspond to better amygdala-PFC connectivity. Cortisol is often seen as a 'brake' to amygdala activity, as increased secretion levels correlate with decreased amygdala activity.[18] A lower SES childhood can dilute the secretion of stress hormones like cortisol, which diminishes amygdala-PFC activity, increasing the individual functioning of both regions.[8] An overactive amygdala and a PFC that cannot properly regulate it leads to an exaggerated response to stress stimuli.[7]

Yet, despite the correlation between living in poverty and harmful effects on the brain, it is paramount to remember that not everyone who has lived in poverty experiences these effects. The findings are worthy of note to be aware of the adverse effects of living in poverty and to remedy the conditions that lead to them. Nevertheless, some research has pointed to skills in some individuals growing up in lower SES conditions that offer them an advantage over their higher SES counterparts. Individuals who grew up in adverse environments have been noted to develop a present orientation, which denotes increased impulsivity and vigilance.[20] The shift in the prioritization of the present is a biological adaptation to perceived unpredictability and less support. This tendency has also been noted to manifest when people who grew up in more supportive environments face rapidly changing environments. While impulsivity can be associated with a lack of regard for

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the future, which is of concern, research has also pointed to enhanced mental abilities.[21] Differences in the type of impulsivity have been distinguished. Notably, 'functional impulsivity' has been defined as acting impulsively when it is optimal instead of 'dysfunctional impulsivity'. Functional impulsivity can be beneficial in high-pressure situations where problem-making is required quickly.[22] Present orientation enables pattern recognition to be more accurate when the period of exposure is shorter, even though, in the long run, it is thought to be worse.[20] Thus, it is possible that the biological adaptations derived from learning to survive in harsher and less supportive conditions demonstrate a form of adaptive intelligence that can be translated toward education and career advancement.

Buffering:

As mentioned, growing up in a lower SES family does not necessarily mean the child will display a disrupted behavioral response to emotional stimuli.[11] Many factors can affect how each individual is shaped by the SES conditions in which they live and how they respond to positive or negative stimuli. Factors such as the parenting style they grew up with and their neighborhoods can buffer the potential stress of a lower SES childhood.[4]

A parent-child relationship provides the child with a safe and secure base. In 2018, Johnson *et al*. conducted a study involving toddlers from various SES backgrounds and differing levels of parental attachment. Cortisol levels did not have as significant a correlation with SES backgrounds as with attachment styles. Children of lower economic status who exhibited symptoms of insecure attachment styles when removed from their parents had increased cortisol levels compared to children of the same socioeconomic status but with secure attachment styles. Nonetheless, the differences in cortisol levels of all children believed to have insecure attachment styles were higher in those from lower SES backgrounds than those from higher SES backgrounds.[4] Having a normal cortisol level higher than the norm indicates lower cortisol secretion in response to fearful or stressful stimuli. This leads to decreased amygdala-PFC connectivity and less-regulated stress responses.[8] Hence, children who develop a secure attachment to their parents have better-regulated responses to stressful situations.

Education, particularly the maternal education level, is an indicator of socioeconomic resources, but it can be argued that it also doubles as a buffer. Good education has the potential to shield the effects of low SES on the brain. In a study conducted by Noble *et al*. in 2015, it was found that children from low-income families with higher education levels showed increased PFC activation and less amygdala activation when performing cognitive control tasks compared to children of similar status but with lower education.[12] This signifies that individuals who received a good education could utilize their PFC more than those who did not complete their education to such a high degree. The amygdala was less activated in those with higher education, indicating it interfered less with the completion of tasks.

Further, parental education, particularly maternal education, influences the effect of SES in childhood. One definition of poverty is low levels of maternal education. Mothers with higher education tend to speak to their children more with a more varied vocabulary. A study by Luby *et al*. in 2013 found that grey matter volume in the PFC in children from low SES families differed depending on the maternal education level. Children whose mothers had a higher level of education correlated with higher grey matter volume in the PFC compared to those whose mothers received a lesser education.[4] Having a well-educated mother or parents who talk to their children regularly can buffer the adverse effects of poverty.

Conclusion

To conclude, this essay has discussed the effects of poverty on the connection between the amygdala and the PFC through the medium of chronic stress in childhood. Individuals who grew up in a lower SES environment are likelier to have weakened amygdala-PFC connectivity, higher amygdala reactivity and reduced PFC volume and activity. Chronic stress signifies that medium cortisol levels are higher than normal, disrupting responses to fearful or stress-inducing events by diluting cortisol secretion when confronted with such stimuli. Lower cortisol secretions reduce the connectivity between the amygdala and the PFC, resulting in each region working harder to compensate for the lack of efficiency lost by the diminished connection. Upon seeing a fearful stimulus, the amygdala will have an exaggerated response, and the PFC cannot properly regulate the response. A reduction in the PFC-amygdala connectivity has a link to later mental health problems, more aggressive behavior, and lower performance in academic contexts. Nevertheless, growing up in poverty does not inherently cause a weakened amygdala-PFC connection. There have been shifts to view the topic of poverty from a more strength-based perspective rather than solely a negative one.

Considering Johnson's and Noble's findings, it is possible to buffer children from the adverse effects of a lower SES. A key mechanism to cope with the impact of poverty on children is a secure attachment to their parents. If the relationship between a parent and the child provides a safe base, the child can have brain development similar to that of their higher SES counterparts. If the parent shields their child from experiencing stress regarding their inability to access proper resources, the child might be significantly less affected by the adversity. Exposure to a positive environment and neighborhood can minimize the adverse effects of low SES. Notably, education has tremendous power over children's brain development.

It is important to note that most studies on the effects of SES on brains, including the amygdala and the PFC, have been conducted in Western countries, predominantly in the US. This limitation denotes that the findings cannot be directly transferred to individuals who live in countries with drastically different social environments than the US.

The findings of poverty's harmful effects on children's brain development should be addressed by public health research. Investing in early intervention programs to provide support to families is imperative so as not to set a child's life in stone. Neuroscientists and policymakers should collaborate to fabricate effective social policies based on evidence. Furthermore, looking to the future, research should be conducted in various countries and socioeconomic contexts. As most of the research has been shown in the US, the field should expand beyond that into other Western and non-western countries, particularly LDCs, where a more significant portion of the population lives in poverty.

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