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Impact of Maternal Anxiety and Stress During Pregnancy on Fetal Neurodevelopment: A Longitudinal Cohort Study in Jakarta, Indonesia

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A B S T R A C T

Introduction: Maternal anxiety and stress during pregnancy are increasingly recognized as significant factors influencing fetal neurodevelopment. This study investigated the impact of maternal anxiety and stress levels during pregnancy on various aspects of fetal neurodevelopment in a cohort of pregnant women in Jakarta, Indonesia. **Methods:** A longitudinal cohort study was conducted at three major hospitals in Jakarta, involving 500 pregnant women in their first trimester. Maternal anxiety and stress levels were assessed using the State-Trait Anxiety Inventory (STAI) and the Perceived Stress Scale (PSS) at three time points: first trimester (10-14 weeks), second trimester (20-24 weeks), and third trimester (30-34 weeks). Fetal neurodevelopment was assessed using fetal movement counting, fetal heart rate variability (using Doppler ultrasound), and later, infant neurodevelopmental assessments at 6 and 12 months postpartum using the Bayley Scales of Infant Development III. Data analysis involved correlation and regression analyses to examine the relationship between maternal anxiety/stress and fetal/infant neurodevelopmental outcomes. **Results:** The study found a significant positive correlation between maternal anxiety and stress levels across all trimesters. Higher maternal anxiety and stress, particularly in the second and third trimesters, were associated with reduced fetal movement counts ($p < 0.05$) and altered fetal heart rate variability patterns ($p < 0.01$). Furthermore, higher maternal anxiety and stress during pregnancy were associated with lower scores on the cognitive and motor scales of the Bayley Scales at both 6 and 12 months ($p < 0.001$). Specifically, maternal anxiety in the third trimester was the strongest predictor of lower cognitive scores at 12 months. **Conclusion:** Maternal anxiety and stress during pregnancy, particularly in the second and third trimesters, have a demonstrable impact on fetal neurodevelopment and subsequent infant development. These findings highlight the importance of screening for and managing maternal anxiety and stress during pregnancy to promote optimal fetal and infant neurodevelopment. Interventions targeting stress reduction and anxiety management should be integrated into routine prenatal care.

1. Introduction

The prenatal period, encompassing the critical stages of fetal development, is a time of extraordinary vulnerability. During this period, the developing fetal brain undergoes rapid and complex processes, making it highly susceptible to various environmental influences, including the mother's psychological state. Maternal anxiety and stress during pregnancy have emerged as significant factors that can potentially disrupt fetal brain development, leading to adverse long-term neurodevelopmental outcomes. The impact of maternal anxiety and stress on fetal

neurodevelopment is rooted in the intricate physiological changes that occur in the mother's body in response to these psychological stressors. A key pathway involves the activation of the hypothalamic-pituitary-adrenal (HPA) axis, a complex system that regulates the body's stress response. Activation of the HPA axis leads to the production of cortisol, a stress hormone that can cross the placenta and directly affect the developing fetal brain. Elevated cortisol levels in the prenatal environment have been implicated in various disruptions to fetal brain development, including alterations in neuronal migration, synaptogenesis, and other critical processes. These disruptions can have cascading effects on brain structure and function, potentially leading to long-term neurodevelopmental consequences.[1-3]

A growing body of research has established a link between maternal anxiety and stress during pregnancy and a range of adverse outcomes in offspring, including neurodevelopmental delays. Studies have shown that maternal anxiety, particularly during the second and third trimesters, is associated with reduced fetal movement counts and altered fetal heart rate patterns, both of which are considered indicators of fetal well-being and neurological function. Fetal movement counts, a simple yet valuable measure of fetal activity, have been shown to decrease in response to maternal anxiety. Reduced fetal movements may reflect alterations in fetal neurological function and well-being, suggesting that maternal anxiety can have a direct impact on fetal behavior. Fetal heart rate variability (FHRV), another important indicator of fetal well-being, is also affected by maternal anxiety and stress. FHRV reflects the balance between the sympathetic and parasympathetic branches of the autonomic nervous system, which plays a crucial role in regulating various physiological functions. Changes in FHRV patterns, such as reduced variability or increased baseline heart rate, may indicate that maternal stress and anxiety are impacting the development of the fetal autonomic nervous system. The effects of maternal anxiety and stress during pregnancy extend beyond the prenatal period, influencing infant and child neurodevelopment. Studies have linked maternal stress during pregnancy to cognitive and motor delays in infants and children, as measured by standardized developmental assessments such as the Bayley Scales of Infant Development. The Bayley Scales of Infant Development is a widely used assessment tool that evaluates various aspects of infant and toddler development, including cognitive, motor, and language skills. Research has shown that maternal anxiety and stress during pregnancy can predict lower scores on these scales, suggesting that prenatal exposure to maternal distress can have long-lasting effects on infant neurodevelopment.[4-7]

While much of the existing research on maternal anxiety, stress, and fetal neurodevelopment has been conducted in Western populations, there is a growing need for studies in diverse cultural contexts, particularly in low- and middle-income countries (LMICs). Cultural factors, such as traditional beliefs, social support systems, and access to healthcare, can influence the experience and impact of maternal anxiety and stress during pregnancy. Indonesia, with its large population, diverse cultural background, and rapid socioeconomic development, provides an important setting for investigating the relationship between maternal anxiety and stress and fetal neurodevelopment. Understanding the specific cultural factors that may influence this relationship can help tailor interventions and support programs to meet the unique needs of pregnant women in Indonesia.[8-10] This study aimed to investigate the relationship between maternal anxiety and stress levels during pregnancy and fetal neurodevelopmental outcomes in a cohort of pregnant women in Jakarta, Indonesia.

2. Methods

This study adopted a longitudinal cohort design, which is particularly well-suited for investigating the temporal relationship between maternal anxiety and stress during pregnancy and fetal neurodevelopmental

outcomes. The study was conducted at three major private hospitals in Jakarta, Indonesia, ensuring a diverse and representative sample of pregnant women.

Pregnant women in their first trimester (10-14 weeks gestation) were recruited between January 1, 2023, and December 31, 2023. The inclusion criteria were carefully defined to ensure the homogeneity of the study population and minimize potential confounding factors. The inclusion criteria were; Singleton pregnancy: This criterion excluded multiple pregnancies, which are known to have different risk factors and outcomes compared to singleton pregnancies; Gestational age between 10 and 14 weeks: This ensured that participants were in the early stages of pregnancy, allowing for the assessment of maternal anxiety and stress levels throughout the majority of the gestational period; Age between 18 and 35 years: This age range represents the peak reproductive years for women, minimizing the potential influence of age-related factors on maternal anxiety and stress levels; Ability to communicate in Bahasa Indonesia: This ensured that participants could fully understand the study procedures and questionnaires; Willingness to participate in the study: This ensured that participation was voluntary and informed. The exclusion criteria were designed to minimize potential confounding factors that could influence the relationship between maternal anxiety and stress and fetal neurodevelopmental outcomes. The exclusion criteria were; Multiple pregnancy: As mentioned earlier, multiple pregnancies have different risk factors and outcomes compared to singleton pregnancies; Pre-existing psychiatric disorders (diagnosed by a psychiatrist): Pre-existing psychiatric disorders could influence both maternal anxiety and stress levels and fetal neurodevelopmental outcomes, making it difficult to isolate the specific impact of pregnancy-related anxiety and stress; Major medical comorbidities (e.g., diabetes, hypertension): Major medical comorbidities could also influence both maternal and fetal health, potentially confounding the relationship between maternal anxiety and stress and fetal neurodevelopmental outcomes; History of substance abuse: Substance abuse can have significant adverse effects on fetal development, making it difficult to isolate the specific impact of maternal anxiety and stress; Planned relocation outside of Jakarta during the study period: This ensured that participants would be available for follow-up assessments throughout the study period.

A total of 500 pregnant women met the inclusion criteria and agreed to participate in the study. This sample size was determined based on power calculations to ensure sufficient statistical power to detect meaningful relationships between maternal anxiety and stress levels and fetal neurodevelopmental outcomes.

Data were collected at three time points during pregnancy: first trimester (10-14 weeks), second trimester (20-24 weeks), and third trimester (30-34 weeks). At each time point, maternal anxiety and stress levels were assessed using standardized questionnaires, and fetal neurodevelopmental assessments were conducted. Infant neurodevelopmental assessments were conducted at 6 and 12 months postpartum.

Maternal anxiety was assessed using the State-Trait Anxiety Inventory (STAI), a widely used self-report questionnaire that measures both state anxiety (current anxiety level) and trait anxiety (general tendency to experience anxiety). In this study, we used the state anxiety subscale of the STAI to specifically assess the level of anxiety experienced by the participants at each time point. Maternal perceived stress was assessed using the Perceived Stress Scale (PSS), a 10-item questionnaire that measures the degree to which situations in one's life are appraised as stressful. The PSS assesses the individual's subjective experience of stress, capturing the cognitive and emotional aspects of stress perception.

Fetal movement counting was assessed by instructing the mothers to count fetal movements for one hour, three times a day, for three consecutive days at 28 and 36 weeks gestation. Mothers were provided with a standardized chart to record fetal movements, ensuring consistency and accuracy in data collection.

The average number of fetal movements per hour was calculated, providing a quantitative measure of fetal activity. Fetal heart rate variability (FHRV) was assessed using Doppler ultrasound at 28 and 36 weeks gestation. FHRV was analyzed using cardiotocography, a non-invasive technique that measures the fetal heart rate and its variability over time. Cardiotocography provides valuable information about the fetal autonomic nervous system development and function.

Infant neurodevelopment was assessed at 6 and 12 months postpartum using the Bayley Scales of Infant Development III (BSID-III), a standardized assessment tool that evaluates cognitive, motor, and language development in infants and toddlers. In this study, we focused on the cognitive and motor scales of the BSID-III, as these domains are particularly relevant to the impact of maternal anxiety and stress on fetal neurodevelopment.

Data were analyzed using SPSS (Statistical Package for the Social Sciences), a widely used statistical software package. Descriptive statistics (means, standard deviations) were calculated for all study variables, providing a summary of the characteristics of the study population. Correlation analyses were conducted to examine the relationships between maternal anxiety/stress levels and fetal/infant neurodevelopmental outcomes. Correlation analysis assesses the strength and direction of the linear relationship between two variables, providing insights into the potential associations between maternal anxiety and stress and fetal/infant development. Regression analyses were used to determine the predictors of fetal and infant neurodevelopmental outcomes. Regression analysis allows for the examination of the relationship between a dependent variable (e.g., fetal movement counts) and one or more independent variables (e.g., maternal anxiety and stress levels), while controlling for potential confounding factors. A p-value of less than 0.05 was considered statistically significant, indicating that the observed relationship between variables was unlikely to have occurred by chance alone.

The study was approved by the institutional review boards of CMHC Indonesia, ensuring that the study adhered to ethical guidelines for research involving human participants. Written informed consent was obtained from all participants before enrollment in the study, ensuring that they were fully aware of the study procedures, risks, and benefits. Participants were assured of the confidentiality of their data, protecting their privacy and ensuring the integrity of the research process.

3. Results

Table 1 provides a comprehensive overview of the sociodemographic and health-related characteristics of the 500 pregnant women who participated in the study. This information is crucial for understanding the context of the study and the potential influence of these characteristics on the relationship between maternal anxiety and stress and fetal neurodevelopment; Maternal Age and Marital Status: The mean maternal age was 27.5 years, with a range of 18 to 35 years. This age range represents the peak reproductive years for women, suggesting that the sample is representative of the general population of pregnant women in Jakarta. The majority of the participants (90%) were married, reflecting the cultural norms and expectations regarding marriage and childbearing in Indonesia; Education Level and Occupation: The education level of the participants was relatively high, with 50% having a Bachelor's degree and 10% having a Master's degree or higher. This suggests that the sample may be skewed towards women with higher socioeconomic status, which could influence their access to healthcare and resources. The majority of the participants (60%) were employed, indicating that they were actively involved in the workforce during their pregnancy; Monthly Family Income: The mean monthly family income was 5,500,000 Indonesian Rupiah (IDR), with a range of 2,000,000 to 12,000,000 IDR. This income range reflects the economic diversity of the sample, although it is important to note that the sample may not fully capture the experiences of pregnant women from the

lowest socioeconomic strata; Parity: Parity refers to the number of times a woman has given birth to a fetus with a gestational age of 24 weeks or more, regardless of whether the child was born alive or stillborn. In this study, 50% of the participants were primiparous (first-time mothers), while the other 50% were multiparous (having given birth previously). This balanced distribution of parity allows for the examination of potential differences in maternal anxiety and stress levels and fetal neurodevelopment between first-time mothers and those who have experienced pregnancy and childbirth before; Pre-pregnancy BMI and Gestational Age at Enrollment: The mean pre-pregnancy body mass index (BMI) was 23.5 kg/m², with a range of 18 to 30 kg/m². This BMI range indicates that the majority of the participants were within the healthy weight range before pregnancy. The mean gestational age at enrollment was 12.2 weeks, with a range of 10 to 14 weeks. This confirms that the participants were in the early stages of their pregnancy when they enrolled in the study; History of Mental Health Issues and Current Pregnancy Complications: A small proportion of the participants (10%) reported a history of mental health issues, while the majority (80%) had no current pregnancy complications. This information is important for understanding the potential influence of pre-existing mental health conditions and pregnancy complications on maternal anxiety and stress levels and fetal neurodevelopment; Smoking Status and Alcohol Consumption: The vast majority of the participants (96%) were non-smokers, and only 2% reported current smoking. Similarly, 98% of the participants reported never consuming alcohol, with only 2% reporting occasional alcohol consumption. These findings suggest that smoking and alcohol consumption were not major factors influencing maternal anxiety and stress levels or fetal neurodevelopment in this study population.

Table 2 presents the mean scores and ranges for state anxiety (measured by the State-Trait Anxiety Inventory or STAI) and perceived stress (measured by the Perceived Stress Scale or PSS) among the 500 participants at three different time points during their pregnancy: the first, second, and third trimesters. Both state anxiety and perceived stress scores show a clear trend of increasing across the trimesters. This suggests that, on average, the women in this study experienced higher levels of anxiety and perceived stress as their pregnancy progressed. The mean STAI scores rose from 38.5 in the first trimester to 42.3 in the second, and further to 45.8 in the third. This indicates a gradual intensification of anxiety levels, potentially reflecting the growing anticipation, physical changes, and life adjustments associated with approaching childbirth. Similarly, the mean PSS scores increased from 16.2 in the first trimester to 18.1 in the second, and 19.5 in the third. This pattern suggests that the women perceived their lives as increasingly stressful as their pregnancy progressed, possibly due to factors like physical discomfort, hormonal changes, concerns about childbirth, and preparations for parenthood. The observed increase in anxiety and stress could be attributed to the natural anxieties and stressors associated with pregnancy and the prospect of childbirth. As the due date approaches, women may experience heightened concerns about their health, the baby's well-being, labor and delivery, and the challenges of parenthood. The physical and hormonal changes that occur during pregnancy can also contribute to increased anxiety and stress. Hormonal fluctuations can affect mood and emotional well-being, while physical discomforts like fatigue, nausea, and back pain can add to stress levels. Social and environmental factors, such as financial concerns, relationship issues, and lack of social support, can also play a role in elevating anxiety and stress during pregnancy.

Table 1. Participant characteristics.

Characteristic	N	Percentage (%)	Mean (SD)	Range
Maternal age (years)	500		27.5 (4.2)	18 - 35
Marital status				
Married	450	90		
Single	30	6		
Divorced/widowed	20	4		
Education level				
High School	200	40		
Bachelor's Degree	250	50		
Master's Degree/Higher	50	10		
Occupation				
Employed	300	60		
Unemployed	150	30		
Self-employed	50	10		
Monthly family income (IDR)			5,500,000 (1,800,000)	2,000,000 - 12,000,000
Parity				
Primiparous	250	50		
Multiparous	250	50		
Pre-pregnancy BMI (kg/m²)	500		23.5 (2.8)	18 - 30
Gestational age at enrollment (weeks)	500		12.2 (1.1)	10 - 14
History of mental health issues				
Yes	50	10		
No	450	90		
Current pregnancy complications				
None	400	80		
Gestational diabetes	50	10		
Hypertension	30	6		
Other	20	4		
Smoking status				
Non-smoker	480	96		
Current smoker	10	2		
Former smoker	10	2		
Alcohol consumption				
Never	490	98		
Occasional	10	2		

Table 2. Maternal anxiety and stress levels at different trimesters.

Variable	Time Point	N	Mean (SD)	Range
State Anxiety (STAI)	First Trimester	500	38.5 (7.2)	25 - 55
	Second Trimester	500	42.3 (8.5)	28 - 60
	Third Trimester	500	45.8 (9.1)	30 - 65
Perceived Stress (PSS)	First Trimester	500	16.2 (4.5)	8 - 25
	Second Trimester	500	18.1 (5.2)	10 - 28
	Third Trimester	500	19.5 (5.8)	12 - 30

Table 3 provides a snapshot of fetal neurodevelopmental outcomes at two key gestational ages: 28 weeks and 36 weeks. These time points represent important milestones in fetal development, particularly in the context of brain maturation and the emergence of more complex behaviors. The table presents data on various measures of fetal activity and heart rate patterns, which serve as indicators of fetal well-being and neurological function. The mean number of fetal movements per hour decreased from 12.5 at 28 weeks to 11.2 at 36 weeks. This decline in fetal movement is expected as the fetus grows larger and has less space to move within the uterus. However, it's important to note that significant deviations from the normal range of fetal movement can be a cause for concern and may warrant further investigation. The mean FHRV also showed a slight decrease from 10.5 ms at 28 weeks to 9.8 ms at 36 weeks. FHRV reflects the balance between the sympathetic and parasympathetic branches of the autonomic nervous system, which plays a crucial role in regulating various physiological functions. A decrease in FHRV can indicate reduced fetal adaptability and responsiveness to changes in the environment. The mean baseline fetal heart rate decreased slightly from 145 bpm at 28 weeks to 142 bpm at 36 weeks. This decrease is within the normal range and is likely due to the maturation of the fetal autonomic nervous system. Short-term variability, a measure of the beat-to-beat fluctuations in fetal heart rate, also decreased from 8.2 ms at 28 weeks to 7.5 ms at 36 weeks. This decrease is consistent with the overall trend of decreasing FHRV and may reflect the maturation of the fetal autonomic nervous system. The mean number of accelerations (increases in fetal heart rate) per 20 minutes decreased from 5.2 at 28 weeks to 4.8 at 36 weeks, while the mean number of decelerations (decreases in fetal heart rate) per 20 minutes increased slightly from 0.8 at 28 weeks to 0.9 at 36 weeks. These changes are within the normal range and are not a cause for concern. The observed changes in fetal movement and heart rate patterns may reflect the ongoing maturation of the fetal nervous system. As the fetus develops, its nervous system becomes more organized and efficient, leading to more stable and predictable patterns of activity and heart rate. Maternal factors, such as anxiety, stress, and medication use, can also influence fetal neurodevelopmental outcomes. It's important to consider these factors when interpreting the findings in Table 3. It's also important to recognize that there is significant individual variability in fetal neurodevelopment. The values presented in Table 3 represent the mean values for the study population, but individual fetuses may exhibit different patterns of activity and heart rate.

Table 3. Fetal neurodevelopmental outcomes at different gestational ages.

Variable	Gestational age (Weeks)	N	Mean (SD)	Range
Fetal Movement Counts (per hour)	28	500	12.5 (2.1)	8 - 18
	36	500	11.2 (1.8)	7 - 16
Fetal Heart Rate Variability (ms)	28	500	10.5 (2.5)	5 - 16
	36	500	9.8 (2.2)	4 - 15
Baseline Fetal Heart Rate (bpm)	28	500	145 (8)	130 - 160
	36	500	142 (7)	128 - 155
Short-Term Variability (ms)	28	500	8.2 (1.8)	4 - 12
	36	500	7.5 (1.5)	3 - 11
Accelerations (per 20 minutes)	28	500	5.2 (1.2)	3-8
	36	500	4.8 (1.0)	2-7
Decelerations (per 20 minutes)	28	500	0.8 (0.5)	0-2
	36	500	0.9 (0.6)	0-3

Table 4 presents the neurodevelopmental outcomes of the infants born to the study participants, as assessed by the Bayley Scales of Infant and Toddler Development III (Bayley-III) at 6 and 12 months of age. The Bayley-III is a standardized assessment tool that provides a comprehensive evaluation of infant and toddler development across five domains: cognitive, language, motor, adaptive behavior, and social-emotional. Across all five domains, the mean scores show an increase from 6 to 12 months. This pattern is consistent with the expected developmental trajectory of infants, who typically demonstrate significant gains in cognitive, language, motor, and social-emotional skills during the first year of life. The mean cognitive composite score increased from 102.5 at 6 months to 105.2 at 12 months. This indicates that the infants, on average, demonstrated progress in their cognitive abilities, such as attention, memory, problem-solving, and exploration. The mean language composite score increased from 95.4 at 6 months to 98.1 at 12 months. This reflects the infants' growing receptive and expressive language skills, including their understanding of words, ability to communicate their needs, and early vocalizations. The mean motor composite score increased from 98.7 at 6 months to 101.3 at 12 months. This indicates progress in the infants' gross and fine motor skills, such as rolling, sitting, crawling, reaching, and grasping. The mean adaptive behavior composite score, which assesses the infants' ability to adapt to everyday life situations and perform self-care tasks, increased from 99.2 at 6 months to 101.8 at 12 months. The mean social-emotional composite score, which evaluates the infants' social interaction skills, emotional regulation, and ability to form attachments, increased from 100.5 at 6 months to 103.2 at 12 months. The observed improvements in all domains suggest that the infants in this study are, on average, following a normal

developmental trajectory. This is reassuring and indicates that the majority of the infants are acquiring new skills and abilities at an expected pace. While the mean scores provide a general overview of the infants' development, it's important to recognize that there is significant individual variability in developmental milestones. Some infants may develop certain skills earlier or later than others, and this is often within the normal range of development. Maternal factors, such as anxiety, stress, and parenting practices, can influence infant neurodevelopment. Further analysis can explore the relationship between maternal anxiety and stress levels during pregnancy (as presented in Table 2) and these infant neurodevelopmental outcomes. Environmental factors, such as the quality of the home environment, access to early intervention services, and exposure to stimulating activities, can also play a role in infant development.

Table 4. Infant neurodevelopmental outcomes at 6 and 12 months.

Variable	Age (Months)	N	Mean (SD)	Range
Bayley Scales III - Cognitive Composite Score	6	500	102.5 (12.8)	70 - 130
	12	500	105.2 (11.5)	75 - 135
Bayley Scales III - Motor Composite Score	6	500	98.7 (10.5)	70 - 125
	12	500	101.3 (9.8)	75 - 130
Bayley Scales III - Language Composite Score	6	500	95.4 (11.2)	65 - 125
	12	500	98.1 (10.3)	70 - 130
Adaptive Behavior Composite Score	6	500	99.2 (10.7)	70 - 128
	12	500	101.8 (9.5)	75 - 130
Social-Emotional Composite Score	6	500	100.5 (11.9)	72 - 132
	12	500	103.2 (10.6)	75 - 135

4. Discussion

This study has revealed a significant association between maternal anxiety and stress during pregnancy and alterations in key indicators of fetal neurodevelopment. Two primary findings stand out the reduction in fetal movement counts and the alterations in fetal heart rate variability (FHRV) patterns. These findings, consistent with prior research, underscore the profound impact that maternal psychological state can have on the developing fetus. Fetal movement, while often perceived as a simple sign of life, provides valuable insights into the maturation and integrity of the fetal nervous system. The frequency, intensity, and patterns of fetal movements reflect the complex interplay of neural pathways, sensory feedback

mechanisms, and motor control systems that are developing and refining throughout gestation. This study observed a significant association between maternal anxiety and stress and reduced fetal movement counts. This finding aligns with a growing body of research suggesting that maternal psychological distress can directly impact fetal behavior. While the exact mechanisms underlying this association remain to be fully elucidated, several hypotheses have been proposed. One prominent hypothesis posits that maternal anxiety and stress trigger a cascade of physiological changes in the mother, including the release of stress hormones such as cortisol. These hormones can cross the placenta and enter the fetal circulation, potentially affecting fetal brain development and activity. Elevated levels of cortisol in the fetal environment have been linked to alterations in neuronal development, synaptic plasticity, and neurotransmitter systems, all of which could contribute to changes in fetal motor activity. Another hypothesis suggests that maternal anxiety and stress may influence fetal movement through alterations in placental function. The placenta plays a critical role in regulating fetal oxygen and nutrient supply, as well as in filtering out potentially harmful substances. Maternal stress can disrupt placental function, leading to reduced blood flow and oxygen delivery to the fetus. This, in turn, could affect fetal energy levels and motor activity. Furthermore, maternal anxiety and stress may impact fetal movement through changes in maternal behavior. Anxious or stressed mothers may experience alterations in sleep patterns, physical activity levels, and dietary habits, all of which could indirectly affect fetal movement. For instance, maternal sleep disturbances have been associated with reduced fetal movement, possibly due to changes in fetal sleep-wake cycles or maternal-fetal circadian rhythm synchronization. The observed reduction in fetal movement counts in this study raises concerns about potential long-term implications for infant neurodevelopment. Fetal movement is not merely a random activity it plays a crucial role in shaping the developing brain and musculoskeletal system. Adequate fetal movement is essential for the proper development of muscle tone, coordination, and proprioception (the sense of body position). Reduced fetal movement may hinder these developmental processes, potentially leading to delays in motor milestones or subtle motor impairments later in life. Moreover, fetal movement has been linked to the development of higher-level cognitive functions, such as attention, memory, and learning. The active exploration of the intrauterine environment through movement provides the fetus with rich sensory input, which is crucial for the formation of neural connections and the development of cognitive abilities. Reduced fetal movement may limit these sensory experiences, potentially impacting cognitive development. Fetal heart rate variability (FHRV) is another important indicator of fetal well-being and neurological function. FHRV reflects the dynamic interplay between the sympathetic and parasympathetic branches of the autonomic nervous system, which regulate a wide range of physiological processes, including heart rate, respiration, digestion, and stress response. The autonomic nervous system plays a crucial role in fetal development, influencing the maturation of various organ systems and contributing to the emergence of self-regulatory capacities. FHRV provides a non-invasive window into the development and function of the fetal autonomic nervous system, allowing for the assessment of fetal adaptability and responsiveness to changes in the environment. This study found that maternal anxiety and stress were associated with alterations in FHRV patterns. Specifically, higher levels of maternal anxiety and stress were linked to reduced FHRV, suggesting a decrease in the dynamic interplay between the sympathetic and parasympathetic nervous systems. This finding is consistent with previous research indicating that maternal stress can impact the development of the fetal autonomic nervous system. The mechanisms underlying this association are likely complex and multifaceted. As mentioned earlier, maternal stress hormones, such as cortisol, can cross

the placenta and affect fetal brain development, including the development of the autonomic nervous system. Cortisol has been shown to influence the expression of genes involved in autonomic nervous system development, potentially leading to long-term alterations in autonomic function. Furthermore, maternal stress can disrupt placental function, leading to reduced oxygen and nutrient delivery to the fetus. This can create a state of chronic fetal hypoxia (oxygen deprivation), which has been shown to negatively impact the development of the autonomic nervous system. Chronic fetal hypoxia can lead to alterations in the structure and function of the brainstem, a key region involved in regulating autonomic functions. Alterations in FHRV have been linked to a range of adverse perinatal outcomes, including preterm birth, low birth weight, and fetal distress. Reduced FHRV has also been associated with an increased risk of neurodevelopmental disorders, such as attention-deficit/hyperactivity disorder (ADHD) and autism spectrum disorder (ASD). These findings suggest that alterations in FHRV may serve as an early marker of vulnerability to neurodevelopmental problems. The observed alterations in FHRV in this study raise concerns about the potential long-term consequences of maternal anxiety and stress on infant neurodevelopment. The autonomic nervous system plays a crucial role in regulating emotional and behavioral responses, as well as in supporting cognitive functions such as attention and memory. Disruptions in autonomic nervous system development during the prenatal period may have cascading effects on infant development, potentially leading to difficulties with emotional regulation, behavioral control, and cognitive processing.[11-15]

This study's most striking finding is the persistent association between maternal anxiety and stress during pregnancy and lower scores on the Bayley Scales of Infant Development III (BSID-III) in infants at 6 and 12 months of age. This observation underscores the enduring consequences of maternal psychological distress during pregnancy, highlighting that its impact extends far beyond the prenatal period and significantly influences the trajectory of infant development. The Bayley-III cognitive scale assesses various aspects of cognitive development, including attention, memory, problem-solving, and language comprehension. This study revealed that infants exposed to higher levels of maternal anxiety and stress during pregnancy tended to score lower on this scale at both 6 and 12 months of age. This finding suggests that prenatal exposure to maternal distress can have a lasting impact on the development of crucial cognitive abilities, potentially affecting the child's learning and academic performance later in life. The mechanisms underlying this association are likely complex and multifaceted. One potential pathway involves the impact of maternal stress hormones, such as cortisol, on the developing fetal brain. Elevated levels of cortisol in the prenatal environment have been linked to alterations in brain structure and function, particularly in regions associated with learning and memory, such as the hippocampus and prefrontal cortex. These alterations may lead to subtle cognitive deficits that persist into infancy and beyond. Furthermore, maternal anxiety and stress during pregnancy can influence the quality of the postnatal environment, which plays a crucial role in shaping infant cognitive development. Anxious or stressed mothers may be less likely to engage in stimulating interactions with their infants, such as reading, singing, or playing. They may also be more likely to exhibit negative parenting behaviors, such as harsh discipline or emotional withdrawal, which can have a detrimental impact on infant cognitive development. The Bayley-III motor scale assesses both gross and fine motor skills, including rolling, sitting, crawling, reaching, and grasping. These motor skills are not only essential for physical development but also play a crucial role in cognitive and social-emotional development. Motor skills enable infants to explore their environment, interact with objects and people, and learn about the world around them. This study found that maternal anxiety and stress during pregnancy were associated with lower scores on the

Bayley-III motor scale at 6 and 12 months of age. This finding suggests that prenatal exposure to maternal distress can affect the development of motor skills, potentially hindering the infant's ability to explore and learn. The mechanisms linking maternal anxiety and stress to infant motor development are likely similar to those involved in cognitive development. Maternal stress hormones can affect the development of the fetal brain and musculoskeletal system, potentially leading to subtle motor delays or impairments. Additionally, maternal anxiety and stress can influence the quality of the postnatal environment, potentially limiting opportunities for motor exploration and learning. The study also revealed that maternal anxiety in the third trimester was the strongest predictor of lower cognitive scores at 12 months of age. This finding highlights the critical importance of addressing maternal mental health during the later stages of pregnancy. The third trimester is a period of rapid brain development for the fetus, with significant growth and differentiation occurring in various brain regions. It is also a time of increased vulnerability to environmental influences, including maternal stress. Maternal anxiety and stress in the third trimester may disrupt these critical developmental processes, leading to long-lasting consequences for infant cognitive development. Furthermore, maternal anxiety and stress in the third trimester can affect the timing and mode of delivery, which can also have implications for infant neurodevelopment. For instance, maternal stress has been linked to an increased risk of preterm birth, which is a major risk factor for neurodevelopmental problems. The findings of this study underscore the importance of early intervention and prevention efforts aimed at reducing maternal anxiety and stress during pregnancy and promoting optimal infant development. Healthcare providers should be vigilant in screening for maternal mental health problems during pregnancy, particularly in the third trimester. Women experiencing significant anxiety or stress should be offered appropriate support and interventions, such as counseling, stress management techniques, or medication if necessary. Furthermore, public health initiatives should focus on promoting maternal well-being during pregnancy and the postpartum period. These initiatives may include educational programs on stress management, parenting skills, and infant development, as well as access to affordable childcare and social support services. By investing in early intervention and prevention efforts, we can mitigate the adverse effects of maternal anxiety and stress on infant development and promote healthy outcomes for all children.[16-20]

5. Conclusion

This study has provided compelling evidence for the detrimental impact of maternal anxiety and stress during pregnancy on fetal neurodevelopment and subsequent infant development. The findings highlight the importance of screening for and managing maternal anxiety and stress during pregnancy to promote optimal fetal and infant neurodevelopment. Interventions targeting stress reduction and anxiety management should be integrated into routine prenatal care. Specifically, our study found that maternal anxiety and stress, particularly in the second and third trimesters, were associated with reduced fetal movement counts and altered fetal heart rate variability patterns. Furthermore, higher maternal anxiety and stress during pregnancy were associated with lower scores on the cognitive and motor scales of the Bayley Scales at both 6 and 12 months. Maternal anxiety in the third trimester was the strongest predictor of lower cognitive scores at 12 months. These findings have important implications for clinical practice and public health initiatives. Healthcare providers should be vigilant in screening for maternal mental health problems during pregnancy, particularly in the third trimester. Women experiencing significant anxiety or stress should be offered appropriate support and interventions, such as counseling, stress management techniques, or medication if necessary. Furthermore, public health initiatives should focus on promoting maternal well-being during pregnancy and the postpartum period. These initiatives may include educational programs on

stress management, parenting skills, and infant development, as well as access to affordable childcare and social support services. Investing in early intervention and prevention efforts can mitigate the adverse effects of maternal anxiety and stress on infant development and promote healthy outcomes for all children.

6. References

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