ASSOCIATIONS BETWEEN SOCIOECONOMIC STRESS, ENGAGEMENT IN JOINT ATTENTION, AND INFANT NEURODEVELOPMENT IN 24- TO 36-MONTH-OLD INFANTS

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Abstract

Associations between maternal socioeconomic stress (SE-stress) at 6 months, quality and quantity of joint attention (JA) at 24 months, and relative alpha and theta activity at rest in 24- to 36-month-old infants were examined. Data from 116 mother-infant dyads from predominantly low-income families were analyzed. Multiple hierarchical regressions indicated significant associations between SE-stress and EEG outcomes, SE-stress and JA quality, and JA quality and 24-month outcomes. Several models tested whether JA quantity/quality mediated or moderated associations between SE-stress and EEG outcomes. A significant moderation effect of JA quantity on the association between stress and theta at 36 months was found, indicating a stronger association between maternal stress and theta power at 36 months when dyads engaged in less JA during play. Overall, findings show SE-stress is associated with both infant resting brain activity and engagement in JA during play. Associations between stress and EEG outcomes vary depending on the quantity of engagement in JA.

Keywords: joint attention, infant neurodevelopment, socioeconomic stress, EEG, theta, alpha

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Associations Between Socioeconomic Stress, Engagement in Joint Attention, and Neurodevelopment in 24- to 36-Month-Old Infants

Infant neural development has been characterized by its rapid synaptogenesis and myelination, which enables the brain to double in size during the first year of life. Neural connections formed during infancy and childhood are particularly influenced by environmental factors. Specifically, consistent, and responsive interactions with caregivers have been found to support healthy brain development (Anderson et al., 2021; Ilyka et al., 2021; Mundy & Jarrold, 2010). In contrast, exposure to high levels of socioeconomic stress (SE-stress) has been associated with neurodevelopmental risk which may influence how children process and interact with the world across their lifespan (Brandes-Aitken et al., 2020).

Explorations of joint attention (JA), originally defined by Scaife and Bruner (1975) as the dyadic interaction between two people sharing attention over a common object or event, have highlighted how the quantity and quality of interactions between children and their caregivers can help scaffold infant neurodevelopment to build essential socioemotional skills (i.e, language, socioemotional cognition, emotion regulation etc.) (Koşkulu et al., 2021; Mundy & Jarrold, 2010). While previous research has found environmental stressors to be associated with variations in JA behaviours (e.g., duration of JA, type of JA) in children over one year old (Abels & Hutman, 2015; Koşkulu et al., 2021), there is a need to clarify how SE-stress experienced during early infancy relates to the development of JA behaviours across the early years. Low family income and low caregiver education have been associated with high levels of parental stress during the infancy period. These variables may affect the quality and quantity of caregiver-child interactions and in turn disrupt typical development of neural networks underlying JA (Brandes-Aitken et al., 2020). However, it is unknown how early SE-stress contributes to

variations in JA interactions that shape the development of neural correlates underlying JA through later infancy and into childhood. This timing is critical as neural foundations underlying JA are established during the first years of life and facilitate the development of the behaviours required to engage in JA interactions (e.g., pointing, following gaze etc.). In turn, engagement in JA further builds and complexifies these neural networks, reflecting the interdependent nature of the relationship between the neural networks underlying JA and engagement in JA. By focusing on the exploration of pathways leading from early life SE-stress to neurodevelopmental change via variations in JA interactions, scientists may gain better insight into the nature and directionality of these associations. The goal of the current study is to investigate the links between socioeconomic stress (SE-stress) during early infancy, quality and quantity of engagement in joint attention (JA) during caregiver-infant play, and baseline neural activity in 24- to 36-month-old infants.

Early Experiences Matter

General associations between environmental factors, including socioeconomic stress, and child development have been explored in depth over the last few decades and highlighted in popular ecological models (Bronfenbrenner, 2000; Masarik & Conger, 2017). During infancy (i.e., birth to 24 months), children remain at the center of their environment, highly sensitive to the effects of their immediate surroundings (i.e., caregivers) while simultaneously exerting their own influence on their environment as they interact with these surroundings. Other distal and proximal environmental variables exert varying degrees of influence (e.g., daycare, extended family, neighbourhood, community). From a neuroscience perspective, early experiences shape the developing brain through experience-driven processes that are particularly active during sensitive periods of neurodevelopment in infancy and early childhood (Greenough et al.,

1987). Indeed, mounting research has explored how perturbations in these neural processes may mediate associations between the early environment and behavioural outcomes in later childhood (see Nelson & Gabard-Durnam, 2020 for a review).

Experience-dependent processes facilitate learning through a process of neural and synaptic growth and pruning which specializes the brain for the unique environment of each individual child. Neural foundations developed during these early periods of rapid neuroplasticity support key facets of children's development, by creating a scaffold on which more complex behaviours and abilities (e.g., language and socioemotional cognition) can be built (Fox et al., 2010). To follow a typical developmental trajectory, these foundations rely on the quality and consistency of the input from the expectable environment. The expectable environment typically prioritizes slow-paced development, where the child can maximize each experience in the environment and extend periods of plasticity which facilitate learning. In contrast, children from socioeconomically stressed environments may need to prioritize a faster pace development, resulting in quicker maturation and earlier attainment of adult-like abilities (McDermott et al., 2021, Nelson & Gabard-Durnam, 2020). The mechanisms underlying these differences remain unclear and may differ depending on the specific circumstances experienced by the child (see McDermott et al., 2021 and Marshall & Fox, 2004 for examples). Disruptions of the expectable environment (e.g., poor nutrition, unstable housing, inconsistent caregiving) may contribute to variation in foundational neural mechanisms and confer risk for atypical neural and behavioural development in later childhood and throughout the lifespan. Neural development models like the experience-dependent model provide a unifying approach to understand how neurodevelopment arises as a result of the child's interactions within their environment and with their caregivers.

Developmental Trajectories of Electroencephalography (EEG) and Neural Correlates of Joint Attention

Understanding typical neurodevelopmental trajectories during infancy provides a helpful framework to evaluate how environmental stressors may alter infant neural development. Both typical neural maturation and experience-driven neurodevelopment have been explored by recording baseline electroencephalography (EEG). EEG is commonly used to measure resting brain activity, employing electrodes placed on the scalp to record electrical signals. Resting EEG assesses brain activity without specific tasks, focusing on frequency (oscillatory speed) and power (amplitude) measures, divided into bands like theta, alpha, beta, and gamma. These bands, although conventionally defined, can vary across studies, with regional oscillations providing additional functional insight within each band. In infancy, theta band oscillations range approximately between 3 and 5 Hz, alpha band oscillations between 6 and 9 Hz, beta band oscillations between 13 and 19 Hz, and gamma band oscillations start at 21 Hz and extend to higher frequencies (De Haan, 2003). These bands, crucially, vary in definition across research studies. Baseline electroencephalography (EEG), which measures neural activity while the child is awake and at rest, has proven helpful in allowing researchers to identify typical and atypical trajectories of infant brain activity during socioemotional development (Perone & Gartstein, 2019; Nunez, 2017; Rayson et al., 2019; Vaughan Van Hecke et al., 2017).

During very early development, alpha rhythms in posterior regions of the brain emerge at approximately 3 Hz during the first few months of life. These early oscillations are thought to reflect neural activity underlying attentional processes (Allen et al., 2004). Low alpha rhythms increase in amplitude as the infant ages and interacts with their environment (i.e., increasing from 3 Hz to 6-9 Hz), fuelling the on-going and accelerated myelination of

corticocortical axons in the brain (Marshall et al., 2002; Mundy & Jarrold, 2010; Nunez, 2007; Saby & Marshall, 2012). Higher resting alpha power in infancy, particularly in frontal regions, has been linked with better executive functioning (Kraybill & Bell, 2013). While consistent evidence supports the role of alpha oscillations in eliciting caregiver-infant interactions (De Haan, 2003; Marshall, Bar-Haimb & Fox, 2002), other low frequency bands such as theta (3-5 Hz), particularly in frontal, central and parietal brain regions, have also been found to facilitate joint attention interactions specifically (Troller-Renfree et al., 2023, see Saby & Marshall, 2012 for a review). Notably, in typically developing infants, power in the theta band and other low frequencies measured during baseline are expected to decrease as the child ages, while power in higher frequency bands, including alpha, tend to increase (De Haan, 2003). However, this typical trajectory might be disrupted in children who experiences high levels of early life stress or psychosocial adversity (Troller-Renfree et al., 2023).

As our understanding of the role of caregiver-infant interactions in shaping infant neurodevelopment becomes more concrete, understanding how engagement in JA may mediate associations between stress and early brain function has become increasingly necessary. Levels of stress stemming from socioeconomic factors (i.e., socioeconomic stress (SE-stress)) experienced by caregivers may account for variations in the quantity and quality of their JA interactions with their children (Koskulu et al., 2021; Lobermeier et al., 2022; Reilly et al., 2021). Thus, including caregiver socioeconomic stress in future models may also clarify pathways by which SES influences infant neurodevelopment. To our knowledge, this study is first to test associations between SE-stress variables, engagement in JA and alpha and theta power during baseline EEG in frontal regions within in a socioeconomically diverse infant sample.

Stress and Baseline Trajectories

In addition to informing our understanding of the mechanisms underlying infant neurodevelopment, the experience-dependent model also provides a strong framework to compare neurodevelopmental outcomes of children from typical backgrounds to those of children from socioeconomically stressed backgrounds, or who have experienced other adverse childhood experiences. Socioeconomic status (SES), often calculated by household income and parent education, has been widely used as a predictor of the quality of a child's environment (Anderson et al., 2021; Vernon-Feagans et al., 2008). Low SES is typically defined as having a lower household income and/or completing fewer years of education compared to high SES counterparts, though other variables such as occupational prestige and income-to-needs ratio are also frequently considered (Anderson et al., 2021; Hurt & Betancourt, 2017). Experiencing low-SES has been associated with elevated stress, as well as increased anxiety and depression symptoms in adults (Lobermeier et al., 2022; Reilly et al., 2021). Collectively, stress stemming from SES factors has been referred to as socioeconomic stress (SE-Stress), and measured using several self-report scales (e.g., Perceived Stress Scale (PSS) and Recent Life Events Questionnaire (RLEQ)). In turn, it has been observed that infants with caregivers experiencing increased SE-stress have increased risk of developing socioemotional and learning difficulties (Borairi et al., 2021; Troller-Renfree, 2022), which may be mediated by the quality and quantity of the interactions between the infant and their caregivers (Borairi et al., 2021; Koşkulu et al., 2021; Perone & Gartstein, 2019).

Comparing neuroimaging data of infants from typical versus socioeconomically stressed environments has revealed some long-term associations between socioeconomic factors (i.e., income and education) and development of neural structure and function (McDermott et al.,

2021, Nunez, 2017). As seen in several EEG studies, infants from low SES and high SE-stress backgrounds display different neural activity, and different patterns of neural development during the first two years of life, compared with their high SES and low SE-stress counterparts (Brander-Aitken et al., 2020; Brito et al., 2016; Pierce et al., 2019; Troller-Renfree et al., 2022; Wilkinson et al., 2023). In contrast to typical baseline trajectories, it has been reported that infants who have experienced early life stress or poverty show an opposite pattern, such that relatively lower power in high frequency bands (i.e., alpha) and higher power in low frequency bands (i.e., theta) has been observed. For example, in a recent exploration of resting EEG in a sample of 12-month-old infants from families experiencing poverty, infants of mothers reporting low SES and high stress (i.e., high SE-Stress) displayed decreased relative baseline alpha and increased relative theta power in frontal and parietal regions, as compared to infants of mothers reporting higher SES and lower stress (i.e., low SE-Stress) (Troller-Renfree, 2023). Similar patterns have also been reported in a sample of 36-month-old Bangladeshi infants, such that higher reports of maternal perceived stress were associated with more absolute theta power in frontal and central regions at 36-months as compared to lower reports of perceived stress (Jensen et al., 2021). However, this association between stress and baseline activity was not significant at 6 months (Jenson et al., 2021), suggesting that the influence of stress on infant neural development may be observable from 12 months (Brito et al., 2016; Troller-Renfree, 2023). Although the functional implications of variation in early EEG patterns remain mixed, a growing body of literature has highlighted the potential role of elevated low frequency band power (including theta) in the diagnosis of Attentional Deficit Hyperactivity Disorder (ADHD) (for discussion, see Lenartowicz & Loo, 2014), such that elevated power in these bands may influence executive control processes early on, associated with more risk taking behaviours in

later childhood (for review, see Anderson & Perone, 2018). Although the functional implications of variation in early EEG patterns remain mixed, consistent evidence links theta and alpha power during infancy to the development of important attention and cognitive control processes (Mundy & Jarrold, 2010; De Haan, 2003). Moreover, a growing body of literature has highlighted the possibility that elevated theta power might be an early indicator of risk for diagnosis of ADHD and challenges with associated executive control processes (Anderson & Perone, 2018).

In addition to how SE-stress may disrupt typical developmental trajectories, there is evidence that SE-stress may disrupt early joint attention (JA) interactions specifically (Koskulu et al., 2021; Lobermeier et al., 2022; Reilly et al., 2021). While prior research has shown SES and stress-based variations across several frequency bands, alpha (6-9 Hz) and theta (3-5 Hz) rhythms may be particularly susceptible to disruption of early JA. Given how strongly alpha power has been linked to the development of attentional processes in frontal, central and parietal regions from 6 months and into early childhood, exposure to environments which do not adequately engage the child during early infancy will likely result in disrupted alpha patterns (i.e., decreases) (Brito et al., 2016; Jensen et al., 2016) and atypical frontal-central-parietal connectivity when measured at rest (Perone & Gartstein, 2019). Theta rhythms, specifically linked to the neural activity underlying JA during caregiver-infant interactions, may follow opposite patterns of disruption (i.e., increases) if the SE-stress experienced by caregivers affects the quality and quantity of their engagement in JA in their daily interactions (Brito et al., 2016; Mundy & Jarrold, 2010). The next sections will review (a) how stress might disrupt early engagement in JA, leading to disruption of these important attentional control networks, and (b)

associations between JA interactions and the development of these networks that may be indexed by theta and alpha power during infancy and early childhood.

Socioeconomic Stress Disrupts Joint Attention Behaviours

Socioeconomic stress (SE-Stress) is thought to contribute to variation in brain development, in part, by influencing the kinds of experiences that children have. One context in which early experiences may be disrupted by SE-stress is engagement in joint attention. Infants and young children are naturally engaged in joint attention (JA) behaviours when they are included in their caregivers' daily activities (e.g., running errands, getting dressed, cooking etc.), which encourages them to respond to and initiate attentional cues within their environment (Mundy & Jarrold, 2010). Child-centered activities like morning and bed-time routines, and play, are also great opportunities for caregivers to engage in meaningful JA with their children (Schneider et al., 2022). The act of engaging in JA, and the experiences encountered through JA, promote synaptic connections in the infant brain which, over time, are thought to establish and refine the neural circuits that support abilities such as attention, language, and socioemotional cognition (Mundy & Jarrold, 2010). As the child engages in more episodes of JA, this early circuitry is strengthened which, in turn, allows for more complex JA behaviours to emerge (Mundy & Jarrold, 2010; Nelson & Gabard-Durnam, 2020; Nunez, 2007).

As discussed in the previous sections, early experiences are associated with aspects of neurodevelopment from very early in infancy. As joint attention (JA) is a key milestone emerging in the second half of the first year of life, it is considered foundational to early language and socioemotional development (Mundy et al., 2007), and exploring how socioeconomic status (SES) predicts early JA interactions can provide insight into the neural

mechanisms underlying socioemotional development. For example, Reilly and their colleagues (2021) found 8- to 18-month-old infants engaged in more, and more sophisticated, use of JA cues when their parents reported greater financial resources and higher levels of education. Consequently, these children may have been better equipped to encode information from their environments (Reilly et al., 2021), resulting in increased quantity and quality in their language production in later infancy and childhood (Betancourt et al., 2015; Brandes-Aitken et al., 2020; Reilly et al., 2021). Although these findings suggest ways in which resource availability associated with high SES (i.e., stable space for play and learning, available caregivers, toys etc.) might optimize behavioural outcomes, Koskulu, Kuntay and Uzundag (2021) were the first to look at the association between SES and the quality and quantity of engagement in JA as mediated by characteristics of maternal behaviours. They found that high SES mothers were more likely to display greater responsivity towards their 12-month-old infants, which in turn elicited greater infant engagement in JA during free play. Variation in the duration, initiation, termination, and type of JA were strongly associated with maternal sensitivity, such that more sensitive mothers engaged in longer and more complex bouts of JA with their infants. In turn, mothers who initiated less and terminated more JA interactions during free play were more likely to report low SES and stressful living conditions (Koskulu et al., 2021). Similarly, other explorations have found that engagement in JA in 15-month-old infants mediated the relationship between attuned caregiving and executive function in late infancy, such that caregivers reporting low SES were significantly less attuned to their child during a naturalistic book reading task, resulting in less engagement in JA and lower scores on measures of executive function at 48 months (Brandes-Aitken et al., 2020). It has been theorized that SE-stress associated with SES and resource instability may elicit negative affect, anxiety and depression in caregivers which

may in turn affect the quantity and quality of JA interactions with their infants (Koskulu et al., 2021; Lobermeier et al., 2022; Reilly et al., 2021). Together, these findings provide evidence that SES-based variations in the quality of engagement in JA are behaviourally observable as early as 8 months of age and attributable to several factors including family income, parent education, parent affect, and responsiveness during caregiver-infant interactions (Brandes-Aitken et al., 2020; Koskulu et al., 2021; Lobermeier et al., 2022; Reilly et al., 2021).

Although we have some understanding of the processes by which JA interactions might be disrupted by SE-stress, there is little evidence for how or whether variations in neural processes underlying JA (e.g., theta power or alpha power) are disrupted in low-SES and high SE-stress contexts. Although studies have observed associations between SES variables and resting EEG (Brander-Aitken et al., 2020; Brito et al., 2016; Jensen et al., 2021; Troller-Renfree et al., 2022; Wilkinson et al., 2023), particularly in high frequency bands (Pierce et al., 2019; Tomalski et al., 2013), no studies have explicitly tested associations between features of engagement in JA and EEG activity in infancy and early childhood. However, studies on other kinds of psychosocial adversity (e.g., institutionalization) have shown significant effects on alpha and theta in infants and young children, such that 22-month-old institutionalized infants displayed increased theta and decreased alpha power compared to their never institutionalized counterparts (Marshall et al., 2004). Thus, while there is strong evidence that SE-stress disrupts JA behaviours and early neurodevelopment, it is unclear whether JA behaviours disrupted by SE-stress mediate the association between SE-stress and the disruption of neural processes underlying JA in late infancy and early childhood.

Social Buffering and Engagement in Joint Attention

Limited access to education and increased financial burdens increase the challenge of caregiving for many reasons. However, considerable variability exists in parenting quality, including within a low-SES context. Thus, high-quality caregiver-child interactions could act as a protective factor for children when families face high levels of stress or severe adversity. For example, research on homeless families with young children found that despite being at an increased risk for developmental delays (e.g., IQ deficits), many children remain well-adjusted within an unstable environment (Haskett, Armstrong & Tisdale, 2016). In this context, positive parenting may have played a significant role (Herbers et al., 2020). By supporting parents and providing them with tools to engage in more responsive caregiving, caregivers may be better equipped to invest in more and better-quality interactions with their children, which may in turn protect them from the adverse developmental outcomes associated with low SES and high SE-Stress environments (Koşkulu, Küntay & Uzundag, 2021, Reilly et al., 2021; Tomalski et al., 2013).

Although factors which may specifically inspire this kind of social buffering remain virtually unknown, a study on the protective effects of maternal growth mindset reported that associations between maternal reports of stress and infant EEG outcomes varied as a function of whether the mother endorsed a growth vs fixed mindset (i.e., belief in their ability to influence their child's development) (Elansary et al., 2022). Infants of mothers with a growth mindset showed no significant differences in EEG power regardless of whether their mothers reported high versus low levels of perceived stress. Conversely, for mothers with fixed mindsets, infant EEG power was lower when mothers reported high stress (Elansary et al., 2022). Despite the novelty of this area of research, these associations provide promising insights into how families

from low SES backgrounds may protect their kids from the neurodevelopmental sequelae associated with exposure to early life stress. Exploring how variation within caregiver-child interactions, such as the quantity and quality of engagement in JA, may moderate (in addition to mediating) associations between maternal stress and infant neural development may provide additional insights for future research in this field.

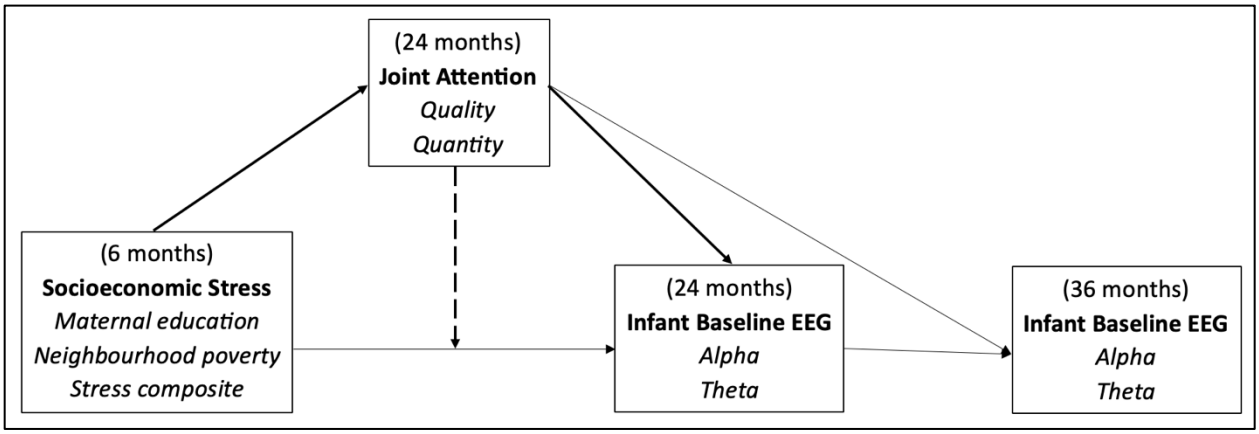
The Current Study

The overall goal of the current study was to investigate associations between maternal socioeconomic stress (SE-stress), quantity and quality of engagement in joint attention (JA) during play, and baseline neural activity in 24- to 36-month-old children. Previously highlighted, including EEG data from early childhood (i.e., 24-36 months) may help explain how socioeconomic stress (SE-stress) in the first year of life (i.e., 6 months) influences engagement in JA during infancy at 24 months, and in turn influences the consolidation of information into proficient attention and JA networks at 24 and 36 months (Jensen et al., 2016; Mundy & Jarrold, 2010). Moreover, there is a strong body of literature supporting the involvement of frontal, central and parietal regions of interest (ROI) during engagement in JA (Mundy & Jarrold, 2010).

The **first objective** of this study was to test whether SE-stress at 6 months was associated with a) quantity and quality of engagement in JA during caregiver-child free play interactions at 24 months, and b) child baseline neural activity (i.e., theta and alpha power) at 24 and 36 months. We predicted higher caregiver SE-stress at 6 months would be associated with less and lower quality engagement in JA at 24 months, higher relative theta power and lower relative alpha power during resting baseline EEG at 24 and 36 months. The **second objective** tested whether associations between caregiver SE-stress at 6 months and child resting EEG at 24 and 36 months are mediated by variations in the quality and quantity of engagement of JA during

play at 24 months. We predicted that caregiver reports of SE-stress at 6 months would be negatively associated with engagement in JA coded during a caregiver-child free-play task at 24 months. We predicted less and lower quality engagement in JA at 24 months will, in turn, be associated with higher relative theta power and lower relative alpha power during baseline EEG at 24 and 36 months. Specifically, we predicted variations in engagement in JA (i.e., duration, frequency, initiation, termination, coordinated vs passive JA) at 24 months would mediate associations between caregiver SE-stress at 6 months and child resting EEG at 24 and 36 months. Multiple regression analyses were computed using relative spectral power to infer the predictive nature of all these variables (Figure 1).

Figure 1. Proposed models



Note. All solid arrows represent hierarchical linear regression paths tested to address aim 1. Bolded solid arrows represent paths tested in mediation models to address aim 2. Dashed arrow represents moderation path tested to address aim 3; EEG = Electroencephalography.

The **third objective** of this study was to examine whether the quality and quantity of engagement in JA during play could buffer against the effects of SE-stress on child neural processing underlying JA. We predicted associations between maternal stress and neurodevelopment would vary as a function of engagement in JA (i.e., quality and quantity) after adjusting for SES variables (i.e., maternal education, neighbourhood poverty), such that negative

associations between maternal stress and infant alpha power and positive associations between maternal stress and infant theta power would be respectively weaker for dyads in which more and better-quality engagement in JA was observed. That is, engagement in more and better-quality JA within a high maternal stress context was expected to act as a buffer against negative effects of maternal stress on early neural development. A moderation analysis tested this aim.

Method

Participants

Mother-child dyads (n = 116) were recruited from the Boston Children's Hospital Primary Care Center in Boston, Massachusetts, and the AltaMed Clinic at Children's Hospital Los Angeles in Los Angeles, California, from January 1, 2016, to March 1, 2018. These clinics predominantly serve families from low-income backgrounds (i.e., below the federal poverty level, qualify for public health insurance). Participant data was excluded if gestational age younger than 37 weeks; birth weight less than 2500 g; identified genetic, metabolic, or neurologic disorders; uncorrected vision difficulties; or birth-related complications (e.g., extended stay in the neonatal intensive care unit). Parents provided written informed consent. The Boston Children's Hospital Institutional Review Board, the Children's Hospital Los Angeles Institutional Review Board and the York University Office of Research Ethics approved all procedures. All data were deidentified to ensure anonymity and confidentiality.

Measures

Demographics

Mothers completed a preliminary screener to confirm their eligibility in the current study when their children were 2 months. Participating mothers provided information on their household income, ethnic background, parent age, work status and parent education. Because not

all participants reported their income, zip code data were used to determine percentage of households below the federal poverty level within each participant's neighborhood as an alternative socioeconomic marker. Caregiver education and neighbourhood poverty served as socioeconomic status metrics for each dyad.

Socioeconomic Status (SES)

Neighbourhood poverty and maternal education were used as metrics for socioeconomic status (SES). Maternal education ratings were recorded as 1 = 8th grade, 2 = some high school, 3 = high school/GED, 4 = associate degree, 5 = bachelor's degree, 6 = master's degree, 7 = MD, JD, PhD or equivalent, and coded into an indicator with 2 categories: high maternal education (i.e., more than high school education) and low maternal education (i.e., high school education or lower).

Stress

Maternal stress was assessed when children were 6 months using the Perceived Stress Scale (PSS; Cohen et al., 1983) and Recent Life Events Questionnaire (RLEQ; based on Brugha et al., 1985). The PSS required mothers to report on a 5-point Likert scale how often they felt or thought a certain way in the past month; examples of the 10 items that comprise the scale include "In the last month, how often have you felt that you were unable to control the important things in your life" and "In the last month, how often have you felt nervous and stressed." A sum score of the items was calculated for each participant at each time point, with positive items reverse scored so that a higher score indicates greater perceived stress and a possible range of 0–40. Each item of the RLEQ describes a life event, such as death of a loved one, and mothers then endorsed whether they experienced that event. A total score was calculated for each participant as the total number of events endorsed, with a possible range of 0–14 with higher scores

indicating more reported events. PSS and RLEQ scores were z scored respectively, summed and the final product was z scored to create a stress composite score for each mother-infant dyad. Neighbourhood poverty, maternal education and the stress composite variables were used separately in analyses to represent the intensity of caregiver socioeconomic stress (SE-Stress).

Engagement in Joint Attention (JA)

Engagement in joint attention was measured via audio- and video-recorded free-play interactions (see Procedure below) between caregivers and children at 24 months. Free-play has been an effective tool for researchers to observe caregiver-child interactions in laboratory settings (Anderson, Perone, & Gartstein, 2022; Schneider et al., 2022; Anderson, Perone, Campagna, & Gartstein, 2021).

Engagement in JA was coded using a coding scheme adapted from previously validated coding systems (Bakeman & Adamson, 1984; Koşkulu, Küntay, & Uzundag, 2021; Tomasello & Todd, 1983). An interaction was coded as JA if both the infant and the mother looked at the same object for at least 3 seconds. Coded dimensions of JA included (1) total duration of JA episodes, and (2) frequency of JA episodes, (3) how JA episodes were initiated and (4) terminated, and (5) whether a JA episode was characterized as passive or coordinated. *Total duration* was defined as the sum of the durations across all JA episodes. *Frequency* was defined as the total number of JA episodes coded during a play session. Initiation of the JA episodes was coded as *Mother Directs* if the episode started with the mother's attempt to shift the attention of the infant to a toy or activity. The initiation was coded as *Mother Follows* if the mother joined into the infant's ongoing focus of attention. Initiation was coded as *Infant Initiated* if an episode started with the infant’s attempt to shift the attention of mother to an object or event by using gestures or vocalizations which clearly demonstrate that gaining mother’s attention is their goal. Ambiguous

gestures or vocalizations followed by mother joining into infant's ongoing focus of attention will be coded as *Mother Follows*. A JA episode was coded as *Terminated by infant (or mother)* if the infant (or mother) looked away from the jointly attended object or activity first for at least 3 seconds. Lastly, we coded the type of JA between the partners as *Passive* if both partners looked at the same object or activity, but the infant showed little awareness of the mother's involvement. A JA episode was coded as *Coordinated* if the infant demonstrated explicit awareness of the mother's involvement through looks to the mother's face, vocalizations, gestures, or turn-taking activities. Mother Directs and Mother Follows, JA Terminated by Infant and JA Terminated by Mother, and Passive and Coordinated categories were mutually exclusive. JA episodes were coded using the ELAN software (Lausberg & Sloetjes, 2009). Half of the coding was done by the first author and the other half was done by an undergraduate student of psychology who was blind to the hypotheses of the study. Fifteen percent of the videos were randomly selected for calculating interrater reliability. Interclass coefficients ranged from .76 to .94 (Koo & Li, 2016). All disagreements were resolved by discussion.

The coded dimensions of engagement in JA were computed into two composite scores to quantify the quantity and quality of engagement in JA. Raw dimension codes were first converted into percentages by dividing each code by the number of JA episodes for each play session. Total duration and frequency of JA episodes during the free-play interactions were adjusted for the total duration of the play interaction in seconds to control for varying play durations, which ranged from 6 to 10 minutes. Adjusted scores were z scored respectively, summed and the final product was z scored to create a JA quantity composite score. The same process was applied to the mother follows, infant terminate and coordinated dimensions to compute a JA quality composite score. Dimensions included in the composite scores were

carefully selected in accordance with the literature on JA and its associations with maternal behaviours during play (Koskulu, 2021; Tamis-LeMonda, Briggs, McClowry & Snow, 2009).

Infant Resting Baseline EEG

Resting EEG was collected from children at 24 and 36 months while they sat on their mother's lap and watched a video of infant toys for up to 5 minutes. Infant recordings were completed using a 128-Channel Hydrocel Sensor Net System (EGI Inc) soaked in a 37°C saltwater solution. Recordings were completed in dimly lit rooms with a low electrical-signal background. Children were 60 cm from a computer monitor (Dell model P2314Ht, 49 × 29 cm) seated and facing forward on their mother's lap. NetAmps 300 Amplifier and NetStation, version 4.5.4 (Boston Children's Hospital) and NetAmps 400 Amplifier and NetStation, version 5 (Children's Hospital Los Angeles) were used to record EEG data. Data were amplified and sampled at 500 Hz while the child watched a video of infant toys for up to 5 minutes (mean impedance, <100 kΩ). Raw EEG data files were exported from NetStation in MATLAB file format (MathWorks, Inc) and pre-processed using HAPPE/BEAPP Pipelines, an automated EEG processing pipeline optimized for use with infant data, to remove electrical line-noise and correct artifacts like high-amplitude eye and motor movements (Gabard-Durnam et al., 2018; Levin et al., 2018). The cleaned data was split into 2-second segments. Remaining artifacts were removed via amplitude-based criteria (+/− 40 uV). Power spectra was extracted from the EEG segments using a fast Fourier transform (FFT) with a multi-taper window on each segment for each channel. The average power spectral density was calculated across all segments for each participant. Log10 transformed absolute spectral data were averaged for theta (4-6Hz) and low alpha (6-9Hz) frequency bands, across all included electrodes. Frequency band ranges were chosen based on prior research on infant neural activity underlying joint attention (Anderson,

Perone & Gartstein, 2022; Mundy & Jarrold, 2010). Relative spectral power was calculated by dividing the power of respective frequency bands by total power. Participants were excluded if their data did not meet sufficient quality requirements (< 20 2-second segments, > 9 channels interpolated during processing, >70% rejected independent components, mean and median probability of artifact in remaining independent components > 0.3). Alpha connectivity values were extracted from pre-processed data using FieldTrip (Oostenveld et al., 2011) following standard procedures for calculation of alpha phase lag index (Haartsen et al., 2020). Measures of a) alpha and theta EEG power, and b) alpha functional connectivity metrics were extracted from the processed EEG data to assess the role of interactivity across frontal, central, and parietal regions. Relative power is often used when EEG has been recorded for multiple age groups during childhood because developmental differences in skull thickness may influence estimates of absolute power (Clarke, Barry, McCarthy, & Selikowitz, 2001).

Procedure

The following section outlines the procedures followed by mother-infant dyads who were followed up longitudinally as part of a cohort study examining responses to early adversity when children were 6, 24 and 36 months old. Mothers provided demographic information and completed the Perceived Stress Scale (PSS) and Recent Life Events Questionnaire (RLEQ) at each time point. Identical protocols were used at each collection site to measure resting baseline activity at 24 and 36 months. Following the EEG procedure, infants engaged in a free-play task with their mothers which lasted an average of 8 minutes. Mothers were given a standard set of age-appropriate toys and instructed to play with their infant “as you would normally”. The play sessions were video, and audio recorded to be coded by the experimenter.

Statistical Approach

To address the first study aim, hierarchical linear regressions were used to test associations between a) SE-stress variables (i.e., maternal education, neighbourhood poverty, and stress composite) and EEG outcomes (i.e., relative alpha and theta) at 24- and 36-months and b) SE-stress variables and JA quality and quantity. Preliminary bivariate Pearson correlations informed the inclusion order of predictors for each regression model. Hierarchical linear regressions were used to test associations between JA metrics and brain outcomes only for cases where JA was predicted by SE-stress (in line with our conceptualization of JA as a mediator). In these cases, relevant SE-stress variables were included as first predictors and relevant JA metrics were included as second predictors to test whether JA metrics and brain outcomes are significantly associated after controlling for relevant SE-stress variables (Baron & Kenny, 1986). Significance was set at $p < 0.05$, 2-sided, for all regression models tested. Significant hierarchical linear regressions informed the inclusion of variables in the mediation models computed to address the second study aim. Specifically, significant associations found between maternal education and theta at 24 months, maternal education and JA quality, and JA quality and theta at 24 months prompted our rationale for a potential mediation effect of JA quality on the association between SE-stress and theta at 24 months. As a result of this decision-making process, the mediation model included maternal education as a predictor, JA quality as a mediator and relative theta at 24 months as the outcome. To address the third study aim, eight moderation models tested whether JA quality and JA quantity moderated associations between maternal stress (i.e., stress composite score) and EEG outcomes (i.e., relative alpha and theta) at 24 and 36 months. The moderation models tested the interaction between the stress composite and JA quantity/quality, controlling for SES variables (i.e., maternal education and

neighbourhood poverty). The stress composite variable was included as the first predictor in all moderation models to reflect the theoretical prediction that associations between maternal stress (i.e., stress composite score) and EEG outcomes would vary as a function of engagement in JA (i.e., quality and quantity) after adjusting for covariates (i.e., maternal education, neighbourhood poverty). SE-stress variables were not all individually included as predictors to minimize the number of models proposed. Significance was set at $p < 0.05$, 2-sided, for all mediation and moderation models tested. The mediation and moderation models did not control for infant age as there were no significant correlations between age and the predictor variables (see Appendix A for full correlation matrix).

Results

Demographics

All data, including caregiver demographics, self-report measures (i.e., PSS, RLEQ, maternal education and neighbourhood poverty) and EEG data, were organized into an excel file and imported into SPSS 29.0. Table 1 summarizes descriptive statistics (i.e., means, ranges, standard deviations) computed for all variables including demographics (i.e., child age, maternal age, race, ethnicity, ethnicity, maternal education, neighbourhood poverty), self-report measures (i.e., PSS and RLEQ), and EEG outcomes (i.e., relative alpha and theta at 24 and 36 months). Descriptive statistics for all dimensions of JA (i.e.., Frequency, total duration, mother directs, mother follows, infant initiates, mother terminated, infant terminated, other terminated, coordinated, passive, and JA quality and quantity composite scores) are summarized in Table 2, where means report the average percentage of JA episodes coded for each dimension for each play session. For example, mean for the *coordinated* dimension represents average percentage of

JA episodes coded as coordinated per play session. *Total duration* mean represents average percentage of time spent in JA per play session. Bivariate Pearson correlations were computed between all the variables mentioned above (refer to Appendix A for full correlation matrix).

Table 1 – Descriptive statistics for demographics, self-report measures and EEG outcome variables.

	N	Range	Mean	SD
Demographics				
Child age in months (6 months)	101	4.9 – 7.4	6.21	.49
Child age in months (24 months)	82	23.1 – 30.4	25.36	1.92
Child age in months (36 months)	66	32.7 – 46.2	37.81	2.45
Child Sex	116			
Male	63			
Female	53			
Maternal Age	116	18 – 42	28.71	5.64
Race	107			
White	56			
Black or African American	36			
Chinese	1			
Filipino	1			
Korean	1			
Vietnamese	1			
Biracial or multiracial	11			
Ethnicity	115			
Not Hispanic, Latino or Spanish origin	47			
Mexican or Mexican American	21			
Puerto Rican	9			
Cuban	1			
Other Hispanic, Latino or Spanish origin	37			
Socioeconomic Status (SES) variables				
Maternal Education	113			
Low (=< high school diploma)	35			
High (> high school diploma)	78			
% Neighbourhood Poverty	110	2– 48	23.7	10.1
Stress variables				
Stress composite score	86	-1.5 – 2.5	0	1
Perceived Stress Scale (PSS)	87	0 – 30	11.75	6.81
Recent Life Events Questionnaire (RLEQ)	99	0 – 7	1.51	1.72
Outcomes				
Relative Alpha (6-9Hz)				
24 months	48	.13 – .23	.18	.02
36 months	36	.12 – .23	.17	.02
Relative Theta (3-5Hz)				
24 months	48	.09 – .15	.13	.02
36 months	36	.09 – .17	.12	.02

[a]N = sample size; SD = Standard Deviation

Table 2 – Descriptive statistics for JA dimensions.

Joint Attention (JA) dimensions (%)	N	Range	Mean (%)	SD (%)
JA Quality composite score	74	-2.04–2.38	0	1
Mother Directs	74	0–.91	51.9	23.1
Mother Follows	74	.05–1	41.3	21.1
Infant Initiates	74	0–.42	6.7	9.5
Mother Terminated	74	.07–.86	41.4	18.8
Infant Terminated	74	.07–.86	53.3	18.8
Other Terminated	74	0–.33	5.1	5.7
Coordinated	74	.33–1	79.9	16.9
Passive	74	0–.67	19.9	16.9
JA Quantity composite score	74	-2.76–2.45	0	1
Frequency[a]	74	.01–.04	2.4	0.8
Total Duration[a]	74	.04–.96	55.4	17.5

Note. Means report the average percentage of JA episodes coded for each dimension for each play session.
[a]Values were adjusted for length of play session in seconds.
N = sample size; SD = Standard Deviation

Objective 1

Hierarchical linear regressions were computed to examine associations between maternal education, neighbourhood poverty, stress, and EEG outcomes (i.e., alpha and theta) at 24 and 36 months in SPSS 29.0 (see Table 3). Regressions were also computed between maternal education, neighbourhood poverty, stress, and JA quality and quantity (see Table 4). A hierarchical approach was used to explore how much additional variance in EEG and JA outcomes was explained by the addition of each individual predictor. Predictor variables (i.e., maternal education, neighbourhood poverty and stress) were therefore entered in 3 separate steps. Maternal education was included as the first predictor, neighbourhood poverty as the second predictor and the stress composite score as the third predictor. Separate regressions were performed for EEG outcomes and JA quality/quantity respectively.

1. Maternal Education, Neighbourhood Poverty, and Stress x EEG Outcomes

Table 3 provides a summary of linear regressions examining associations between maternal education, neighbourhood poverty, stress, and EEG outcomes (i.e., relative alpha and theta) at 24 and 36 months.

No significant associations were found at step 1 or step 2 of the model predicting alpha power at 24 months. A significant amount of variance in alpha power at 24 months was explained by step 3 of the model, including all three predictors (R^2 = .126, $F(3) = 1.688$, p = .187, *F Change* = 4.369, p = .044). Within this model stress significantly and positively predicted alpha power at 24 months (B = .007, p = .044), adjusting for maternal education and neighborhood poverty. A near significant trend was observed between stress and alpha at 36 months (B = .006, p = .093).

A significant amount of variance in theta power at 24 months was explained by step 1 of the model, with only maternal education included as a predictor (R^2 = .112, $F(1) = 4.65$, p = .037). Within this model maternal education was significantly and negatively associated with theta power (B = -.010, p = .037). Inclusion of additional variables in steps 2 and 3 of the model did not explain additional variance in 24-month theta. None of the models explained significant variance in relative alpha or theta at 36 months.

Table 3 - Linear regressions examining associations between maternal education, neighbourhood poverty, stress, and EEG outcomes.

	Alpha (24 mo) B [95% CI] *p*	**Alpha (36 mo)** B [95% CI] *p*	**Theta (24 mo)** B [95% CI] *p*	**Theta (36 mo)** B [95% CI] *p*
Step 1				
Maternal Education	.004 [-.011,.020] .586	.007 [-.012,.026] .439	-.010 [-.019,-.001] .037*	.000 [-.016,.016] .985
Model Statistics	R^2 = .008 Adj R^2 = -.019	R^2 = .022 Adj R^2 = -.013	R^2 = .112* Adj R^2 = .088	R^2 = .000 Adj R^2 = -.036
Step 2				
Maternal Education	-..004 [-.013,.020] .658	.007 [-.012,.026] .445	-.009 [-.018,.000] 0.053^{+}	.000 [-.016,.016] .984
Neighborhood Poverty	-.021 [-.092,.051] .565	-.030 [-.106,.045] .416	.015 [-.026,.056] .457	.011 [-.053,.075] .725
R^2 Change	.009	.024	.014	.005
Step 3				
Maternal Education	.007 [-.009,.023] .382	.008 [-.010,.026] .373	-.010 [-.019,.000] 0.41	.001 [-.015,.017] .927
Neighborhood Poverty	-.007 [.838,-.077] .838	-.026 [-.099,.048] .478	.012 [-.030,.053] .565	.014 [-.050,.078] .656
Stress	.007 [.000,.014] .044*	.006 [-.001,.014] .093^{+}	-.002 [-.006,.002] .412	.004 [-.003,.010] .239
R^2 Change	.109*	.100	.017	.053

[a]Reported are unstandardized β coefficients on first row, 95% confidence intervals on second row, and p values on third row. $^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$

2. Maternal Education, Neighbourhood Poverty, Stress x JA Quality and Quantity

Table 4 provides a summary of linear regressions examining associations between maternal education, neighbourhood poverty, stress and JA quality and quantity. A significant amount of variance in JA quality was explained by step 1 of the model including only maternal education as a predictor (R^2 = .116, $F(1) = 7.112$, p = .01). Maternal education was significantly and positively associated with JA quality (B = .763, p = .01). While maternal education remained a significant

predictor at each step of the model, the inclusion of neighborhood poverty and stress did not explain additional variance in JA quality. None of the models explained significant variance in JA quantity.

Table 4 - Linear regressions examining associations between socioeconomic status, stress, JA quality and quantity.

	JA Quality B [95% CI] *p*	**JA Quantity** B [95% CI] *p*
Step 1		
Maternal Education	.763 [.189,1.336] .010**	-.114 [-.720,.492] .707
Model Statistics	R^2 = .116** Adj R^2 = .100	R^2 = .003 Adj R^2 = -.016
Step 2		
Maternal Education	.742 [.166,1.319] .013*	-.085 [-.690,.520] .778
Neighborhood Poverty	-1.154 [-3.703,1.396] .368	1.623 [-1.053,4.299] .229
R^2 Change	.014	.027
Step 3		
Maternal Education	.748 [.167,1.329] .013*	-.082 [-.693,.529] .788
Neighborhood Poverty	-1.078 [-3.662,1.507] .407	1.666 [-1.052,4.383] .224
Stress	.069 [-.193,.332] .599	.039 [-.237,.315] .778
R^2 Change	.005	.001

[a]Reported are unstandardized β coefficients on first row, 95% confidence intervals on second row, and p values on third row. $^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$

3. Maternal Education and JA Quality x EEG Outcomes

Given the significant associations found between maternal education and EEG outcomes and maternal education and JA quality, linear regressions were computed to test maternal education and JA quality as predictors of EEG outcomes at 24 and 36 months (see Table 5). A significant amount of variance in theta at 24 months was explained by step 1 of the model including only maternal education as a predictor (R^2 = .086, $F(1) = 4.255$, p = .045). A significant amount of variance in theta at 24 months was also explained by step 2 of the model including maternal education and JA quality as a predictor (R^2 = .169, $F(2) = 4.487$, p = .017). While maternal education remained a significant predictor at each step of the model, the inclusion of JA quality explained additional variance in theta at 24 months (B = .004, p = .042). The models did not explain significant variance in alpha at 24 months or 36 months or theta at 36 months.

Table 5 - Linear regressions examining associations between Maternal Education, JA Quality and EEG outcomes.

	Alpha (24 mo) B [95% CI] *p*	**Alpha (36 mo)** B [95% CI] *p*	**Theta (24 mo)** B [95% CI] *p*	**Theta (36 mo)** B [95% CI] *p*
Step 1				
Maternal Education	.006 [-.008,.020] .412	.001 [-.018,.020] .905	-.008 [-.016,.000] .045*	-.005 [-.016,.007] .401
Model Statistics	R^2 = .015 Adj R^2 = -.007	R^2 = .001 Adj R^2 = -.039	R^2 = .086* Adj R^2 = .066	R^2 = .028 Adj R^2 = -.011
Step 2				
Maternal Education	.005 [-.010,.020] .475	-.001 [-.021,.020] .952	-.011 [-.019, -.002] .012*	-.007 [-.019,.006] .269
JA Quality	.001 [-.006,.008] .807	.002 [-.007,.011] .641	.004 [.000,.008] .042*	.002 [-.003-.008] .360
R^2 Change	.001	.009	.083*	.034

[a]Reported are unstandardized β coefficients on first row, 95% confidence intervals on second row, and p values on third row; JA = Joint Attention. $^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$

Objective 2

A mediation model was computed to test whether JA quality mediated associations between maternal education and relative theta at 24 months in SPSS 29.0 using Model 4 of the PROCESS Toolbox (Hayes, 2022). Mediations were not computed for EEG outcomes at 36 months or alpha at 24 months given no significant associations were observed between the predictor variables (i.e., maternal education and JA quality) and 36-month outcomes or alpha at 24 months, reported in the previous section (see Table 5). Mediation results are summarized in Table 6.

Table 6 – Summary of mediation analysis for theta at 24 months.

EEG Outcome	**Theta (24mo)**						
	N	R2	F	p	B	SE	p
Model	47	.075	3.667	.062^{+}			
Mediating variable: JA Quality					.004	.002	.042*
Maternal Education					-.011	.004	.012*

[a]Reported are model values for N = sample size, R^2 = R coefficient squared, F = variance, and p = significance indicator, and variable values for B = β coefficients, SE – standard error, and p.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$

Model findings support maternal education (B = -.011, p = .012) and JA quality (B = .004, p = .042) as significant predictors of relative theta at 24 months. The model explained a nearly significant amount of variance in theta at 24 months (R^2 = .075, F = 3.667, p = .062). The direct effect of maternal education on theta at 24 months was significant after accounting for JA quality, b = -.011, CI = [-.019, -.003], p = .012. No significant indirect effects were observed, indicating no mediation effect of JA quality on the association between maternal education theta at 24 months.

Objective 3

The third goal of the study was addressed by running a moderation analysis in SPSS using Model 1 of the PROCESS Toolbox (Hayes, 2022) to test whether quality and/or quantity of engagement in JA moderates associations between caregiver SE-Stress variables at 6 months and infant baseline EEG. Eight moderation models tested associations between stress (composite) and EEG outcomes (i.e., relative theta and alpha) at 24 and 36 months (see Tables 7 and 8; see Appendix B for all moderation plots). These models included the stress composite score as the first predictor of EEG outcomes, and maternal education and neighbourhood poverty as covariates, and, finally, the interaction between stress (composite) and JA (quality or quantity, respectively). The decision to include the stress composite variable as the first predictor in all moderation models was influenced by our theoretical prediction that associations between maternal stress (i.e., stress composite score) and EEG outcomes would vary as a function of engagement in JA (i.e., quality and quantity) after adjusting for covariates (i.e., maternal education, neighbourhood poverty). Significant findings are presented below.

Table 7 – Summary of moderation analysis for relative alpha and theta at 24 months.

EEG Outcome	**Alpha (24mo)**						
	N	R2	F	p	B	SE	p
Model 1	38	.096	.679	.642			
Moderating variable: JA Quality					.000	.004	.944
Stress composite					.006	.004	.116
Neighbourhood Poverty					.001	.036	.974
Maternal Education					.008	.008	.361
JA Quality x Stress composite					.001	.004	.912
Model 2	38	.105	.752	.591			
Moderating variable: JA Quantity					-.002	.004	.607
Maternal Education					.008	.008	.347
Neighbourhood Poverty					.002	.036	.957
Maternal Education					.008	.008	.347
JA Quantity x Stress composite					-.002	.005	.347
	Theta (24mo)						
	N	R2	F	p	B	SE	p
Model 3	38	.353	3.484	.013*			
Moderating variable: JA Quality					.007	.002	.003*
Stress composite					-.003	.002	.181
Neighbourhood Poverty					.019	.019	.323
Maternal Education					-.013	.004	.005**
JA Quality x Stress composite					.0004	.002	.869
Model 4	38	.176	1.369	.262			
Moderating variable: JA Quantity					.001	.002	.766
Stress composite					-.002	.002	.289
Neighbourhood Poverty					.009	.022	0.676
Maternal Education					-.009	.005	.076^{+}
JA Quantity x Stress composite					-.003	.003	.371

[a]Reported are model values for N = sample size, R^2 = R coefficient squared, F = variance, and p = significance indicator, and variable values for B = β coefficients, SE = standard error, and p.

Stress composite refers to the stress composite score which includes maternal reports on the Perceived Stress Scale (PSS) and Recent Life Events Questionnaire (RLEQ).

$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$

Table 8 – Summary of moderation analysis for relative alpha and theta at 36 months.

EEG Outcome	**Alpha (36mo)**						
	N	R2	F	p	B	SE	p
Model 5	21	.638	5.276	.005**			
Moderating variable: JA Quality					.006	.003	.106
Stress composite					.013	.003	<.001**
Neighbourhood Poverty					-.019	.024	.448
Maternal Education					-.009	.007	.259
JA Quality x Stress composite					.001	.003	.821
Model 6	21	.564	3.882	.019*			
Moderating variable: JA Quantity					.000	.004	.938
Stress composite					.014	.003	.001**
Neighbourhood Poverty					-.017	.027	.541
Maternal Education					-.002	.008	.785
JA Quantity x Stress composite					-.001	.004	.843
	Theta (36mo)						
	N	R2	F	p	B	SE	p
Model 7	21	.495	2.937	.048*			
Moderating variable: JA Quality					.004	.003	.175
Stress composite					.002	.003	.446
Neighbourhood Poverty					.055	.021	.019*
Maternal Education					-.01	.007	.131
JA Quality x Stress composite					-.004	.003	.237
Model 8	21	.513	3.154	.038*			
Moderating variable: JA Quantity					.000	.003	.939
Stress composite					.001	.003	.712
Neighbourhood Poverty					.054	.021	.02*
Maternal Education					-.000	.006	.942
JA Quantity x Stress composite					-.008	.003	.027*

[a]Reported are model values for N = sample size, R^2 = R coefficient squared, F = variance, and p = significance indicator, and variable values for B = β coefficients, SE – standard error, and p.
Stress composite refers to the stress composite score which includes maternal reports on the Perceived Stress Scale (PSS) and Recent Life Events Questionnaire (RLEQ).
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$

Model 1 and model 2 did not explain significant variances in alpha power at 24 months.

Model 3 explained a significant amount of variance in theta power at 24 months (R^2 = .353, F = 3.484, p = .013). The model findings support maternal education (B = -.013, p = .005) and JA quality (B = .007, p = .003) as significant predictors of relative theta at 24 months. The interaction term was not significant, indicating no moderation effect of JA quality on the association between the stress composite and theta at 24 months.

Model 4 was not significant but supported maternal education as a near significant predictor of theta at 24 months (B = -.009, p = .076).

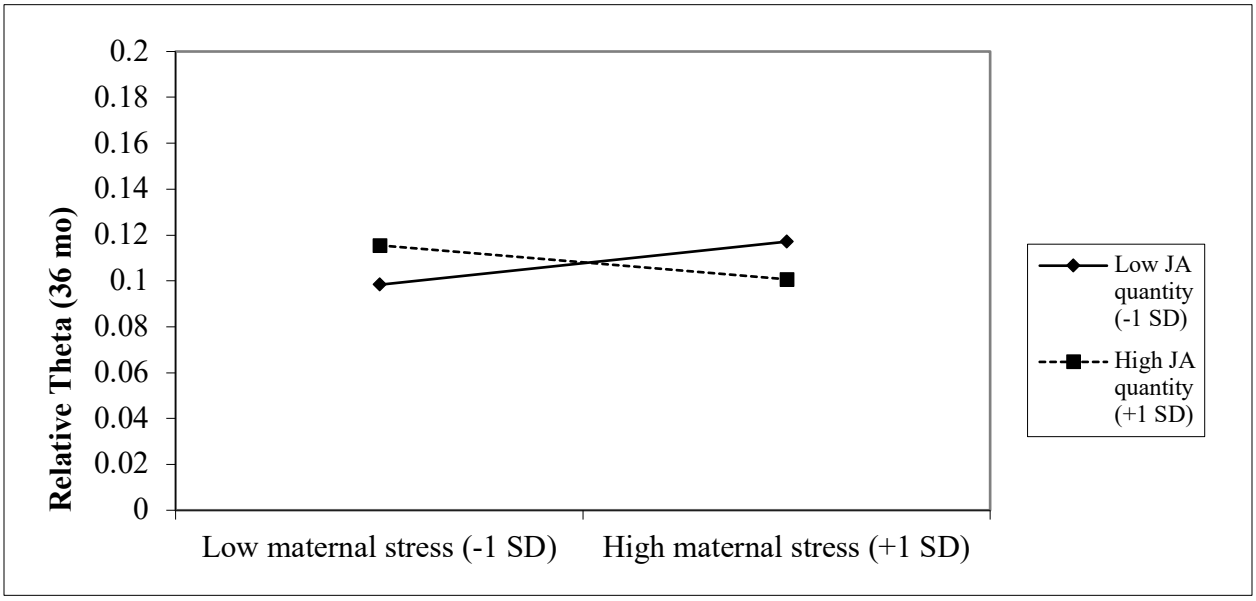
Model 5 explained a significant amount of variance in alpha at 36 months (R^2 = .638, F = 5.276, p = .005). The model findings support stress (B = .013, p = <.001) as a significant predictor of relative alpha power at 36 months. The interaction term was not significant, indicating no moderation effect of JA quality on the association between the stress composite and alpha at 36 months.

Model 6 explained a significant amount of variance in alpha at 36 months (R^2 = .564, F = 3.882, p = .019). The model findings support stress (B = .014, p = .001) as a significant predictor of relative alpha power at 36 months. The interaction term was not significant, indicating no moderation effect of JA quantity on the association between the stress composite and alpha at 36 months.

Model 7 explained a significant amount of variance in alpha at 36 months (R^2 = .495, F = 2.937, p = .048). Neighbourhood poverty was a significant predictor of theta at 36 months (B = .055, p = .019). The interaction term was not significant, indicating no moderation effect of JA quantity on the association between the stress composite and alpha at 36 months.

Model 8 was the only model to yield a significant interaction term, supporting a moderation effect of JA quantity on the association between the stress composite and theta at 36 months (B = -.008, p = .027; see Figure 2). The model explained significant variance in theta power at 36 months (R^2 = .513, F = 3.154, p = .038). In addition, the main effect of neighbourhood poverty in the prediction of theta at 36 months was significant (B = .054, p = .02). The association between the stress composite and theta power at 36 months was significant at low levels of JA quantity (B =.011, SE = 004; p = .019), but not at mid (B =.000, SE = 003; p = .967) or high levels of JA quantity (B =-.007, SE = 005; p = .171) (see Figure B.8 in Appendix B for moderation plot).

Figure 2. Model 8 moderation interaction plot for relative theta at 36 months.



Discussion

The current study explored associations between maternal socioeconomic stress (SE-stress) variables (i.e., maternal education, neighbourhood poverty and maternal stress composite score), quality and quantity of joint attention (JA) during play, and infant EEG outcomes (i.e., relative alpha and theta power) at 24 and 36 months. Findings from the hierarchical regressions computed to address the first study objective revealed a significant association between the stress composite and relative alpha at 24 months, with nearly significant trending associations at 36 months. Significant associations were also found between maternal education and theta at 24 months, maternal education and JA quality at 24 months, and JA quality and theta at 24 months; however, JA quality did not significantly mediate the association between maternal education and theta at 24 months when tested to address the second study objective. The moderation analyses computed to address the third study objective yielded a significant moderation effect of JA quantity on the association between maternal stress (i.e., stress composite) and theta at 36 months, wherein the association between stress and theta power at 36 months was significant at low levels of JA quantity, but not at mid or high levels. JA quality was not a significant moderator of the association between stress and alpha at 24 months or 36 months. JA quality or quantity were not predicted by other SE-stress variables.

Significant associations were found between maternal education and infant relative theta power at 24 months, maternal education and JA quality at 24 months, and JA quality and relative theta at 24 months. Consistent with our predictions, mothers reporting lower levels of education were more likely to engage in lower quality JA with their infants. Infants whose mothers reporting lower levels of attained education were more likely to display higher resting theta power at 24 months. These associations support previous findings whereby mothers with more education are more likely to engage in higher quality interactions with their children (Koskulu et

al., 2021; Ronfani et al., 2015) and have children who are more likely to display lower low frequency brain activity (i.e., theta) at rest (Anderson & Perone, 2018, Troller-Renfree, 2023). These findings together contribute to a mixed body of literature examining the influence of maternal education on infant development. While some studies have not reported significant associations between maternal education and developmental outcomes, and others find other socioeconomic metrics to be stronger predictors (see Mensch et al., 2019 for a review), there is evidence to support both the direct and indirect influence of maternal education on child outcomes (see Bacharach & Baumeister, 1998 and Tong et al., 2007 for examples). For example, while previous findings have supported a mediating effect of home environment (AIRE "promotion of autonomy" subscale) and family SES in the association between maternal education and cognitive and language development in an Italian 18-month-old sample, the significance of these models vary depending on the outcomes of interest (e.g., cognitive, language, motor) and the predictors included (i.e., maternal education, SES, AIRE scores) (Rofani et al., 2015). In this context, the researchers suggest promotion of autonomy within the home environment seems to play a crucial role in infant cognitive, language and motor development at 18 months, where mothers with more education are more likely to foster this type of home environment. Other factors associated with high maternal education may also support optimal child development (see Le & Nuygen, 2020 for a review and discussion). First, mothers with more years of education are more likely to work when their infants are 12 months or older (Le & Nuygen, 2020). While working mothers may have less time spent with their child, they are more likely to enjoy increased earnings and allocate more resources to improve the quality of their child's environment. Adjacently, working mothers are more likely to have fewer children, enabling these mothers to allocate more resources per child than may be possible in families with

more children. Some evidence suggests that a smaller sibship is associated with increases in the child's quality of life (i.e., greater likelihood of school enrollment and better academic achievement) (Li, Zhang & Zhu, 2008). Additionally, effects of maternal education on child health and development are also thought to act through access to information and resources, where highly educated mothers are more likely to have greater access to information and health resources (Thomas et al., 1991), including access to prenatal care (Liu et al., 2017), compared with mothers who report lower levels of attained education. While our current understanding of the role of maternal education on infant development remains unclear and context-dependent, our findings suggest that maternal education could potentially serve as a valuable predictor of the quality of mother-infant interactions during play, which may in turn influence infant resting neural activity at 24 months. Future investigations including a larger sample size are necessary to support this conclusion.

Partially consistent with our predictions, regression models testing associations between SE-stress variables and EEG outcomes revealed a significant positive association between the stress composite score and relative alpha power at 24 months. Infants of mothers reporting more stress were more likely to display higher resting alpha at 24 months. Trend level associations were also observed between the stress composite and relative alpha power at 36 months as well. Although associations between stress and EEG outcomes were expected, the direction of the associations reported are opposite to the predicted trajectories, at both time points. While previous literature has demonstrated lower alpha power at rest in a socioeconomically stressed sample at 12 months (Troller-Renfree, 2023; Troller-Renfree, 2020) and 36 months (Jensen et al., 2016), our results suggest 24-month-olds were significantly more likely to display higher alpha power when their mothers reported higher levels of stress. Several factors may have contributed to these findings.

First, the stress composite included maternal scores on the Perceived Stress Scale (PSS) and the Recent Life Events Questionnaire (RLEQ). Preliminary bivariate correlations indicated a significant positive correlation between PSS scores and relative alpha at 24 months, but RLEQ scores were not significantly correlated to any of the EEG outcomes (refer to Appendix A for full correlation matrix). It is worth noting that although scores in this sample spanned a broad range for the PSS (i.e., scores ranged from 0 to 30 out of a maximum of 40 points), the highest score obtained on the RLEQ was a 7; half of the potential score (i.e., 14). Thus, while no mothers reported experiencing every stressor listed on the RLEQ, some mothers reported feeling highly stressed on the PSS. The PSS may be a better predictor of alpha development at 24 months than RLEQ in our sample, however, this does not clarify why the direction of the association is opposite to what we predicted. It may be that measures of perceived and objective stress represent unique sources of variance in neurodevelopmental outcomes. Second, the fact that associations observed in the present study were in the opposite direction to those reported in the literature may reflect the observation that alpha power increases across infancy and early childhood (De Haan, 2013). However, this is unlikely given child age in this sample was not correlated with stress composite scores nor PSS and RLEQ scores respectively. While previous studies reporting negative associations between maternal stress and infant alpha activity map onto our current sample age and EEG frequency ranges included (Jensen et al., 2016; Troller-Renfree, 2021), some have observed that alpha activity in younger infants (i.e., 6 months) is most prominent in frontal areas, whereas for the 36-month-old children alpha activity is most prominent in central and parietal regions, a pattern that resembles that observed in adults (Jensen et al., 2016). Given our current analyses include only alpha and theta activity in frontal regions in older infants, this discrepancy may account for the direction of the association we report between

stress and alpha. Alternatively, it could be that mothers reporting some elevated stress when their infants were 6 months were better able to buffer their infants from environmental stressors in our sample than mothers reporting lower levels of perceived stress. Similar interpretations have been made in studies assessing the mediating effect of maternal responsiveness on the association between neonatal risk (conceptualized as an SES factor) and child cognitive outcomes (IQ), such that neonatal risk was related to less maternal sensitivity only when maternal anxiety symptoms were above average levels, but not when anxiety symptoms were low (Egotubov et al., 2020). Future streams of research may consider the protective nature of low or moderate maternal stress on infant neural development. Third, some scientists have hypothesized that exposure to stressed environments may lead to accelerated neural maturation in young children, reflecting the brain's rapid adaptation to its environment (McDermott et al., 2021; Nunez, 2017). In turn, these children are more likely to display more mature patterns of neural development, which could explain the positive association between stress and alpha in our current sample. It's notable that the body of literature linking stress with early neurodevelopment includes mixed results, with both positive and negative associations frequently observed (see Olson, Chen, & Fishman, 2021 for review). This points to the need to carefully consider individual differences in factors such as age, SES (etc.) across studies to understand relationships across the spectrum of early development.

As previously mentioned, regression models that tested associations between SE-stress variables and JA metrics (i.e., quality and quantity) demonstrated that maternal education was positively associated with JA quality, partially supporting our predictions. While neighbourhood poverty and caregiver reports of stress did not significantly predict JA quantity or quality, mothers reporting higher education were more likely to engage in higher quality JA during free

play interactions at 24 months. Because reported stress and neighbourhood poverty were not associated with JA quality or quantity, it may be that maternal education reflects variables or experiences that are more proximal to the child at this stage of development (ex. Sensitive maternal behaviours; Koskulu et al., 2021). For example, higher education might buffer against negative experiences related to income or stress, which might occur more distally to the child. We also observed that JA quality predicted theta power at 24 months when maternal education was included as a covariate, such that infants of mothers engaging in higher quality JA interactions during play displayed higher relative theta at 24 months. This observation was contrary to our predictions that better JA quality would be associated with lower theta power, as the direction of this association suggests that engagement in lower quality JA is – counterintuitively – associated with more optimal theta activity at rest. While this observation was unexpected, it might be the case that different features of the JA quality composite score were associated with maternal education and theta power, respectively. To probe this possibility, we considered the pattern of bivariate correlations between each JA dimension included in the JA quality composite score (i.e., mother follows, infant terminated, and coordinated) and maternal education and theta power respectively. While bivariate correlations were not significant, patterns suggested that infant termination of joint attention was the component of JA most strongly associated with theta power at 24 months, while correlations between theta power and both mother follows and coordinated interactions were near zero. In contrast, significant positive correlations were observed between maternal education and coordinated episodes of JA. Interestingly, the discrepancies between these associations may suggest that while the association between maternal education and JA quality is driven by the coordination of JA behaviours, the association between JA quality and theta at 24 months may be driven by infant termination of

JA. While infant termination can reflect a more "child-led" JA interaction, it is also possible that it reflects higher levels of infant inattention. Previous literature has demonstrated that higher resting theta activity can be a predictor of attentional difficulties like ADHD in later childhood (Anderson & Perone, 2018). It may therefore be the case that, in this sample, infants might terminate more episodes of JA as a function of a smaller attentional span during play, which subsequently predicts higher theta power. This speculative explanation would benefit from follow-up in a larger sample with the statistical power to tease apart associations with individual JA metrics.

Given significant associations between maternal education and JA quality, and JA quality and relative theta power at 24 months, a mediation model was run to test whether JA quality mediated associations between maternal education and theta power at 24 months. Interestingly, while we previously demonstrated significant associations between maternal education and JA quality and JA quality and relative theta power at 24 months, JA quality did not significantly mediate the relationship between maternal education and theta power at 24 months. Maternal education and JA quality remained significant predictors of theta at 24 months. These findings suggest that the relationship between SE-Stress and the theta power is not significantly explained by engagement in JA. While we acknowledge the near significance of the mediation model could be explained by the small sample size included in the analysis, it is likely that the mediation effect is not be coming through due to the earlier mentioned directional differences observed between maternal education and theta, which was negative, and JA quality and theta, which was positive. While we expected to find that infants of less educated mothers to display higher theta power at rest and for those mothers to engage in lower-quality JA during play, we did not expect engagement in lower-quality JA to predict optimal (i.e., lower) theta activity. This directional

discrepancy warrants the probing of other interpretations which might have influenced our findings, and which should be considered in future investigations.

Accordingly, it may be that additional variables relating to the sensitivity or responsivity of maternal behaviours contributes to variation in JA behaviours during play. For example, prior work has found that higher-SES mothers were more sensitive, less controlling, provided more cognitive stimulation, and displayed more positive affect, and these behaviours mediated associations between SES and JA quality (i.e., episodes initiated by mother following) and quantity (i.e., longer JA episodes) between caregivers and their 12-month-old infants (Koskulu et al., 2021). Other studies have also supported JA to be an operating mechanism by which attuned caregiver behaviors predict the development of higher-order cognitive abilities in later infancy, and wherein the effect of joint attention would be amplified for children living in elevated poverty (Brandes-Aitken et al., 2020). Therefore, additional features of the caregiver-child interaction might better explain links between SE-stress and early neural development. Moreover, although the study by Koskulu, Kuntay and Uzundag (2021) included a socioeconomically diverse sample, participants were all recruited from Poland, which limited the cultural diversity of the sample. The sample in the present study consisted mainly of Hispanic and Black dyads, who may have different play styles compared to their White counterparts, and hence different ways of engaging in JA. For example, while previous studies on predominantly White samples highlight mother following into their child's play as optimal compared to directing the play (Koskulu et al., 2021), or support specific types of home environments as optimal (Rofani, 2015), similar studies with Black and Hispanic mothers report more mother directing behaviours during play compared to following behaviours (Tamis-LeMonda et al., 2009). These differences may reflect how infants from different cultural backgrounds may learn

different JA interaction styles in their environment, a theory underlying the eco-cultural model of parenting (Keller, 2007). Additionally, evidence suggests that, in some contexts, redirection (as opposed to follow-in) is in fact positively associated with child language outcomes (see Shimpi & Huttenlocher, 2007 for example). However, another study that included a sample of Latin American (Argentinian) mothers and their 9- to 13-month-old infants also found that mothers rated as more sensitive on the Early Mother-Child Interaction Coding System were more likely to engage in better quality JA (i.e., more coordinated JA) (Simaes et al., 2022). Whether the type of JA initiation (i.e., directs vs follows) predicts sensitive maternal behaviours remains unclear, however there is evidence supporting that more sensitive mothers are more likely to engage in higher quality JA interactions, initiated by mother following-in to the child's play (Koskulu et al., 2021). Therefore, what constitutes a high-quality JA interaction might vary depending on context and individual cultural differences. Exploring associations between SE-stress and individual dimensions of JA might reveal a more nuanced relationship between these variables, specifically when explored within a socioeconomically and culturally diverse sample. While the present study was first to explore associations between dimensions of JA and neural outcomes in 24- to 36-month-olds, incorporating maternal behaviours such as sensitivity into the proposed model may also help explain how maternal SE-stress might influence infant neurodevelopment via the quality of interactions during play.

Another aim of the project was to test whether engagement in high quality and quantity JA might buffer negative associations between SE-stress and neurodevelopment. Moderation analyses revealed a moderation effect of JA quantity on the association between stress and theta at 36 months, while controlling for neighbourhood poverty and education. Specifically, at low levels of the moderator (i.e., JA quantity) there was a positive relationship between stress and

theta. In contrast, there was no significant relationship at mid or high levels of JA quantity, suggesting that the impact of stress on theta depends on the level of JA quantity. At low levels of JA quantity during play, maternal stress appears to have a stronger and significant positive association with theta power at 36 months. This suggests that when mothers and infants engage in less JA interactions during play, maternal stress might have a more pronounced impact on the infant's resting theta activity. Conversely, at moderate to high levels of JA quantity during play, the relationship between maternal stress and resting theta was not significant. This finding supports our third prediction and suggests engagement in more JA (i.e., more frequent, and longer episodes) during play buffered the positive association between maternal stress and increased theta activity at 36 months. However, we did not observe that JA quantity or quality significantly moderated associations between stress and any other EEG outcome. Given the small sample size included in the moderation analyses, our findings are worth replicating in a larger sample and are to be interpreted cautiously. While there is evidence that the quality of play interactions may be a better predictor of infant outcomes (e.g., language production) compared to the quantity of these interactions (Rowe, 2012), our results are consistent with previous studies where increased frequency of infant JA behaviours during semi-structured infant-researcher play were observed in higher-income infants compared to their lower-income counterparts (Abels & Huntman, 2015). While our JA behaviours were observed during unstructured mother-infant play, our findings highlight how the frequency and duration of JA interactions during play may still serve an important role in buffering children’s neurodevelopment from the adverse effects of socioeconomic stress. Though associations between stress and EEG outcomes did not vary as a function of JA quality, our results still highlight the importance of stress and maternal education as a consistent predictor of resting theta activity and further suggests that other factors like JA

quantity and maternal sensitivity may be influencing the relationship between SE-stress variables and relative theta at 36 months. This interpretation adheres to previous hypotheses derived from the eco-cultural model of parenting, where infants from families with different socioeconomic status learn to interact with their environment differently (Keller, 2007). In turn, investigating the influence of maternal and infant behaviours, culture, and SE-stress on underlying essential cognitive processes like JA may create a better understanding of how mothers actively scaffold their children's neural development in their daily interactions, and how current social systems can appropriately support caregivers with limited resources and reduce barriers to active participation in their children's development.

Limitations

This project includes several limitations which should be acknowledged. First, the mediation results discussed should be interpreted with caution given the mediator (i.e., JA quality at 24 months) and the outcome variable (i.e., theta at 24 months) were assessed at the same time point. This complicates our ability to establish temporal precedence as it becomes challenging to determine whether the quality of JA preceded and in turn influenced 24-month brain outcomes, or whether the brain activity preceded the quality of JA. In turn, the risk of reverse causation is heightened, whereby the outcome variable may influence the mediator, confounding the mediation effects and threatening the internal validity of the findings. Accordingly, this discrepancy could have led to erroneous interpretations of causality if our proposed mediation model had yielded a significant indirect effect. However, given the near significance of our mediation model, it is also possible that our inability to capture the dynamic neural processes occurring in infants when engaged in JA over time may obscure the tested mediation pathway. Because the play sessions and EEG recordings were recorded at the same

time point, our interpretation cannot fully grasp the nature of the association between the maternal SE-stress and infant relative theta power at 24 months. Second, the longitudinal nature of the data included in the analyses heavily impacted our sample size in the mediation and moderation analyses included to address aims 2 and 3. While the interpretations of the findings are discussed, our methods are worth replicating with a larger sample and are to be interpreted with caution. Future research exploring the influence of play interactions on associations between stress and infant EEG outcomes will also benefit from incorporating mediator and outcome data at multiple time points to establish adequate temporal precedence in future models.

Third, although the current study aims to explore intricacies within mother-infant interactions during play, play sessions within a laboratory setting may alter the natural interactions that may occur during play in the home. While play interactions for participants from the Boston testing site were recorded without any investigators visible, participant from the Los Angeles testing site were present during play sessions which prompted certain children to turn their attention towards the investigators instead of their mother. In turn, the reported quality and quantity of JA engagement coded during play sessions may not provide a completely accurate representation of the JA engagement occurring in the natural environment, which may affect interpretations of the data. In addition, the dimensions of JA which contributed to the JA quality composite scores were chosen in accordance with the literature on optimal forms of play and joint attention (Koskulu et al., 2021; Tamis-LeMonda, Briggs, McClowry & Snow, 2009). However, optimal forms of play may be culture dependent; while mother following behaviours are thought to reflect better initiation of play than mother directing behaviours in predominantly White samples, Black and Hispanic mothers may favour directing behaviours during play. Thus,

it is possible that the operationalization of the JA quality composite score may not reflect the play preferences for our current sample.

Conclusion

The context of this study is set in a reality where disproportionate rates of children and their families experience adversities associated with poverty and low rates of formal education (Zhang & Bernard, 2022; U.S. Census Bureau, 2022). While previous research has extensively investigated the effects of low socioeconomic status (SES) and stress on developmental outcomes, less is known about how socioeconomic stress (SE-stress) affects the development of the underlying processes that foster learning and socioemotional development, like joint attention (JA). This study investigated how maternal SE-stress at 6 months is associated with the quality and quantity of JA at 24 months to make inferences as to how these factors influence resting alpha and theta activity at 24 and 36 months. Our findings support associations between SE-stress and EEG outcomes, SE-stress and JA quality, and JA quality and EEG outcomes at 24 months. Moderation analyses yielded a significant moderation effect of JA quantity on the association between stress and theta at 36 months. The mediation and moderation models tested did not support JA quality as a significant mediator or moderator of the path between SE-stress and EEG outcomes. Although the role of JA quality and quantity during play interactions in supporting early neurodevelopment remains unclear, these metrics may contribute to variances in resting brain activity for infants of mothers reporting high SE-stress. Future research in this area may benefit from exploring metrics to quantify the quality and quantity of interactions between mothers and their infants, and the intricate influence of culture and socioeconomic stress, to better understand how parents help scaffold their children's neural development through their daily interactions. This project contributes to larger body of literature which aims to contest the

stigma surrounding SES and childhood outcomes, by deterring researchers from placing blame on caregivers for the outcomes of their children when systemic factors present barriers to the quality of their relationship which may be out of their control.

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Table A – Bivariate correlations between all variables.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. Child age (6 months)	1																							
2. Child age (24 months)	.269*	1																						
3. Child age (36 months)	0.034	.337**	1																					
4. Neighbourhood poverty	-0.033	-0.151	0.207	1																				
5. Maternal Education	0.139	0.12	-0.083	-.244*	1																			
6. Stress composite score	0.012	0.184	-0.019	-0.052	-0.028	1																		
7. Recent Life Events Questionnaire (RLEQ)	-0.018	0.11	0.016	-0.043	0.035	.830**	1																	
8. Perceived Stress Scale (PSS)	-0.01	0.239	-0.039	-0.029	-0.112	.842**	.398**	1																
9. JA Quality composite score	-0.005	0.177	0.1	-0.138	.276*	0.016	0.211	-0.113	1															
10. Mother Directs	-0.05	-0.081	0.18	.282*	-0.159	0.069	-0.099	0.167	-.596**	1														
11. Mother Follows	0.045	0.139	-0.177	-.325**	0.175	-0.066	0.102	-0.193	.600**	-.911**	1													
12. Infant Initiates	0.005	-0.114	-0.058	0.039	0.006	-0.025	0.018	0.021	0.13	-.412**	0.001	1												
13. Mother Terminated	-0.002	-0.198	-0.073	0.12	-0.097	-0.005	-0.201	0.101	-.744**	.294*	-.317**	-0.036	1											
14. Infant Terminated	-0.046	0.193	0.065	-0.063	0.095	0.023	0.229	-0.091	.716**	-0.196	.229*	-0.01	-.952**	1										
15. Other terminated	0.158	0.043	0.068	-0.178	-0.001	-0.045	-0.053	-0.026	0.09	-.289*	.246*	0.167	-0.139	-0.161	1									
16. Coordinated	-0.006	-0.006	.297*	0.137	.237*	0.077	0.065	0.075	.523**	0.011	-0.125	.248*	-0.099	0.088	0.082	1								
17. Passive	0.006	0.009	-.294*	-0.133	-.242*	-0.077	-0.066	-0.075	-.519**	-0.011	0.13	-.261*	0.097	-0.085	-0.082	-.999**	1							
18. JA Quantity composite score	-0.215	-0.191	-0.105	0.091	0.117	0.017	0.037	-0.002	.309**	-.248*	0.169	.233*	-0.078	0.053	0.088	.346**	-.352**	1						
19. Frequency	-.246*	-.249*	-0.131	0.159	0.033	-0.127	-0.125	-0.085	0.015	0.069	-0.136	0.131	0.083	0.036	-.354**	0.126	-0.13	.685**	1					
20. Total Duration	-0.037	-0.013	-0.014	-0.041	0.128	0.15	0.185	0.083	.409**	-.409**	.367**	0.188	-0.189	0.036	.475**	.348**	-.352**	.685**	-0.063	1				
21. Relative Alpha (24 months)	-.405**	-0.186	-0.069	-0.059	0.095	.314*	0.165	.315*	0.069	0.156	-0.141	-0.072	-0.22	0.246	-0.197	0.039	-0.039	0.016	0.139	-0.111	1			
22. Relative Alpha (36 months)	-0.043	-0.023	-0.124	-0.149	0.154	0.322	0.122	0.313	0.098	0.128	0.118	-.540**	-0.116	0.113	0.011	-0.036	0.036	0.033	-0.115	0.164	.558**	1		
23. Relative Theta (24 months)	-0.088	-0.176	0.032	0.164	-.292*	-0.081	-0.146	-0.015	0.196	-0.099	0.101	0.019	-0.186	0.249	-0.243	0.035	-0.035	0.121	0.191	-0.027	0.087	-0.189	1	
24. Relative Theta (36 months)	0.124	0.083	-0.044	-0.016	-0.053	0.237	0.106	0.247	0.111	0.035	0.068	-0.227	0.094	0.055	-.454*	0.107	-0.107	-0.094	0.083	-0.201	0.188	.390*	0.327	1

$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$

Appendix B – Moderation Plots

Figure B.1 – Model 1 moderation plot testing JA quality as a moderator between stress and alpha power at 24 months. No statistically significant moderation observed.

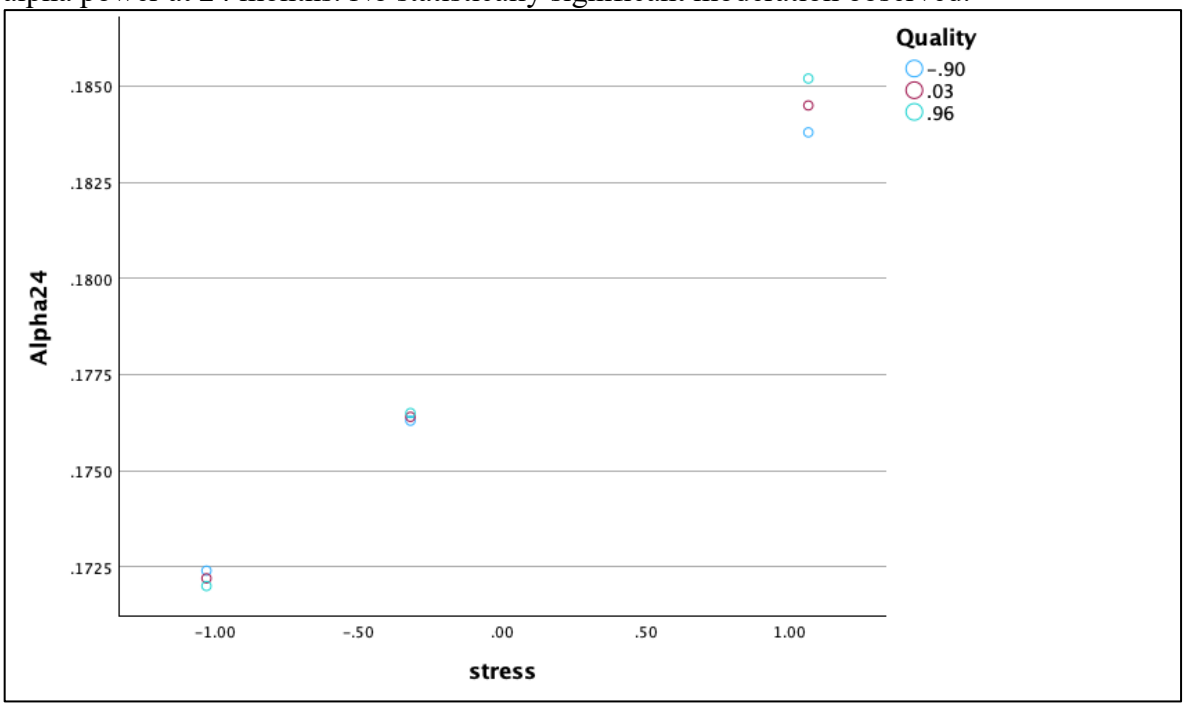

Figure B.2 – Model 3 moderation plot testing JA quality as a moderator between stress and theta power at 24 months. No statistically significant moderation observed.

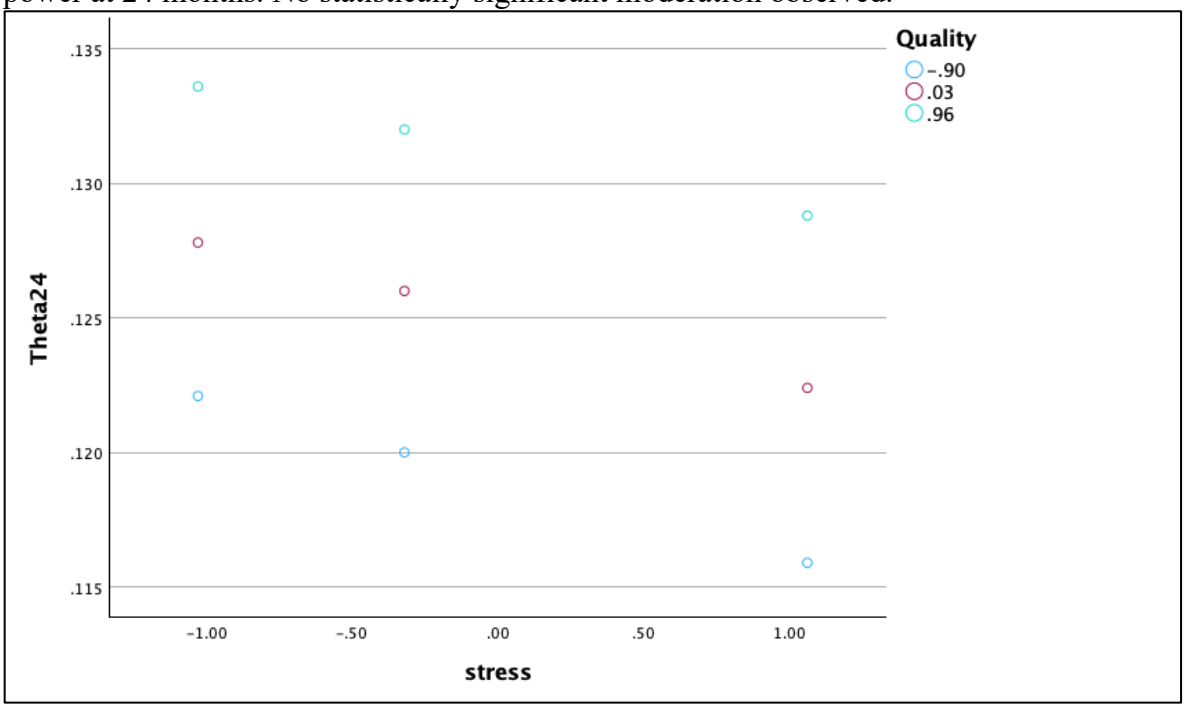

Figure B.3 – Model 5 moderation plot testing JA quality as a moderator between stress and alpha power at 36 months. No statistically significant moderation observed.

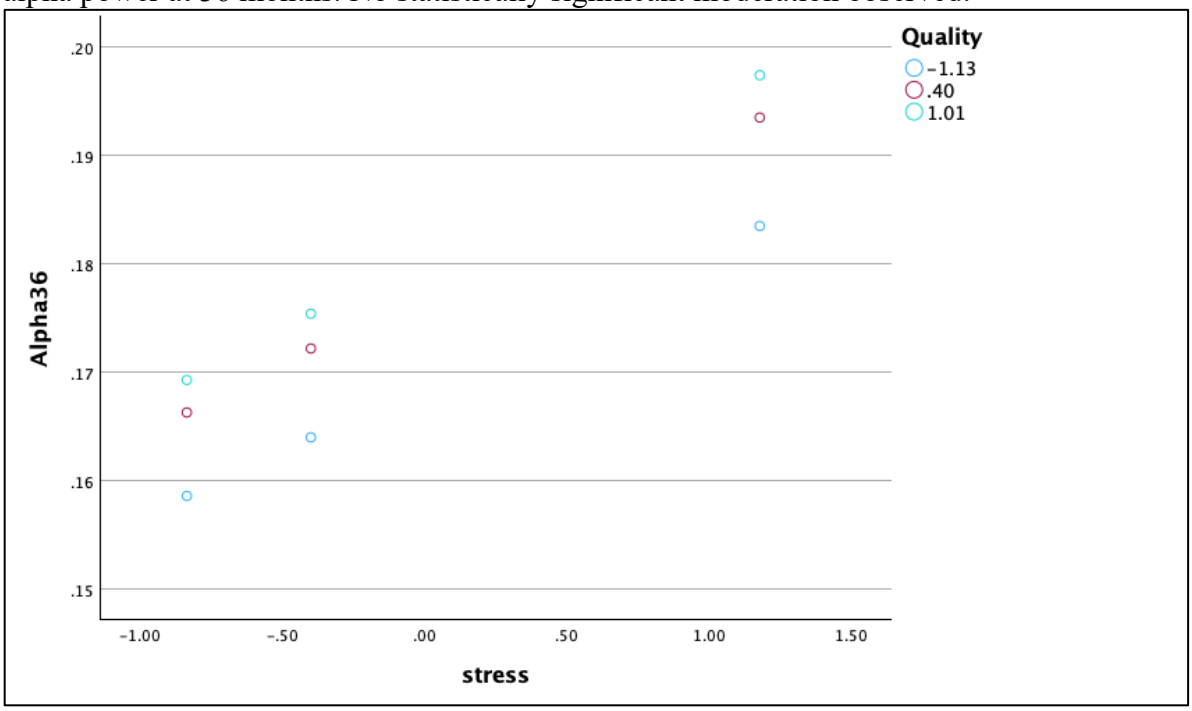

Figure B.4 – Model 7 moderation plot testing JA quality as a moderator between stress and theta power at 36 months. No statistically significant moderation observed.

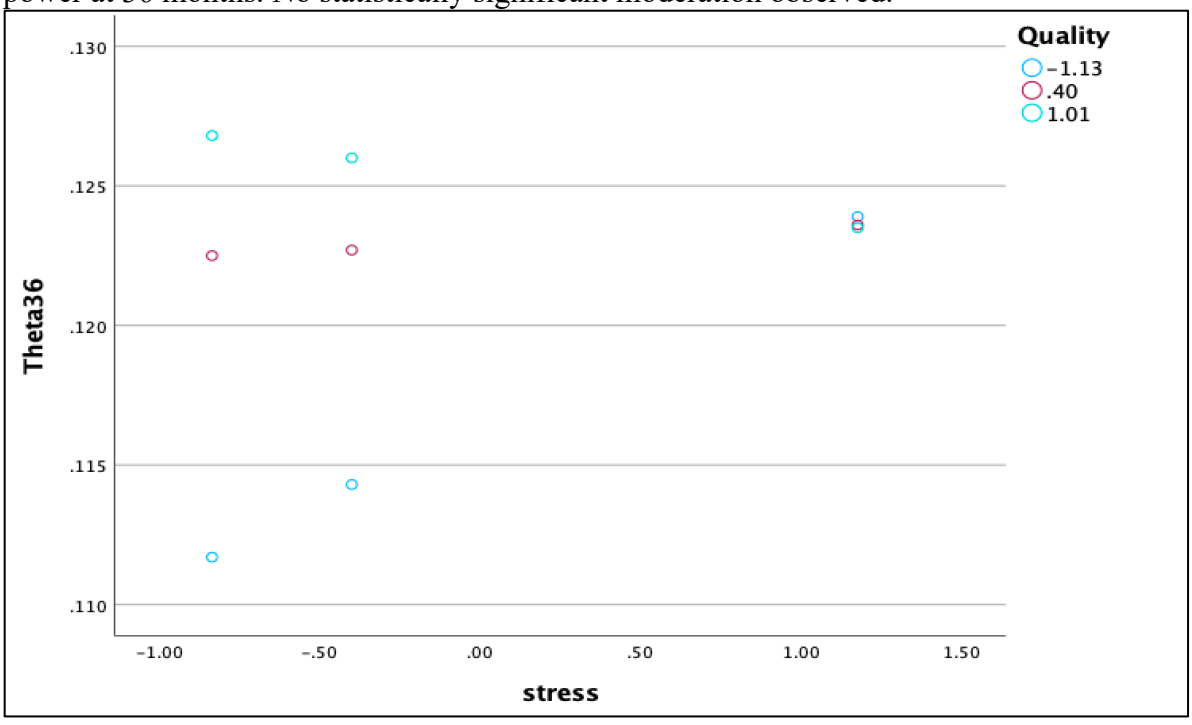

Figure B.5 – Model 2 moderation plot testing JA quantity as a moderator between stress and alpha power at 24 months. No statistically significant moderation observed.

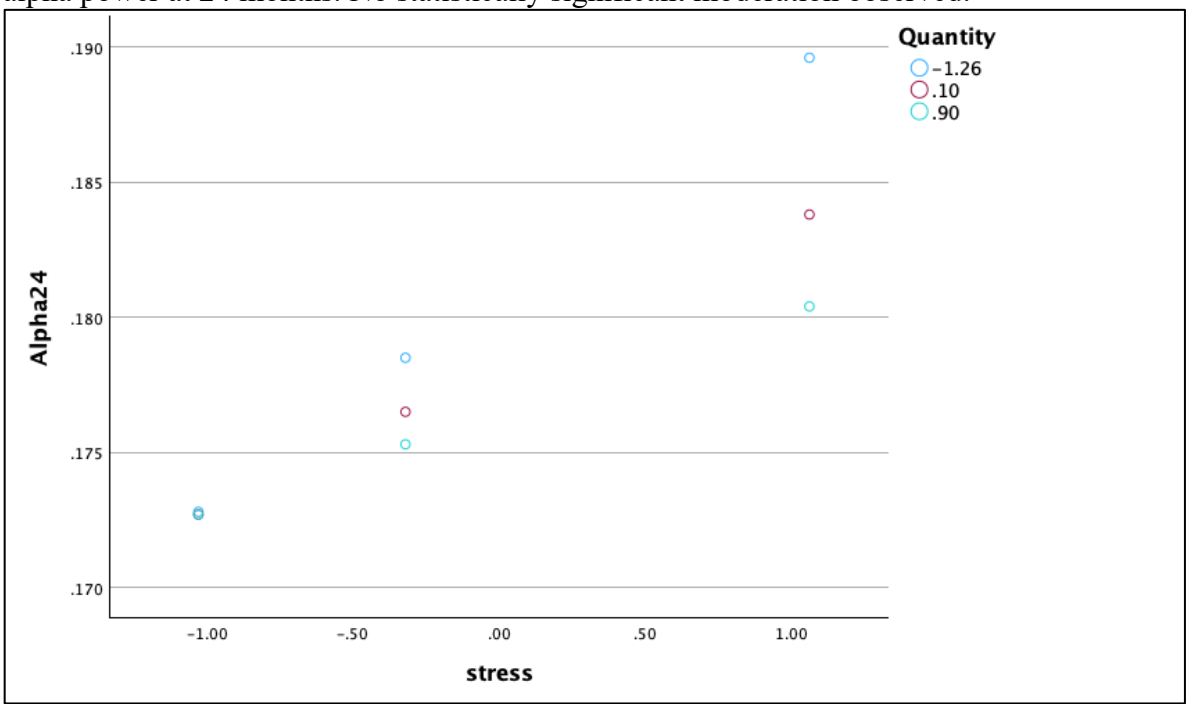

Figure B.6 – Model 4 moderation plot testing JA quantity as a moderator between stress and theta power at 24 months. No statistically significant moderation observed.

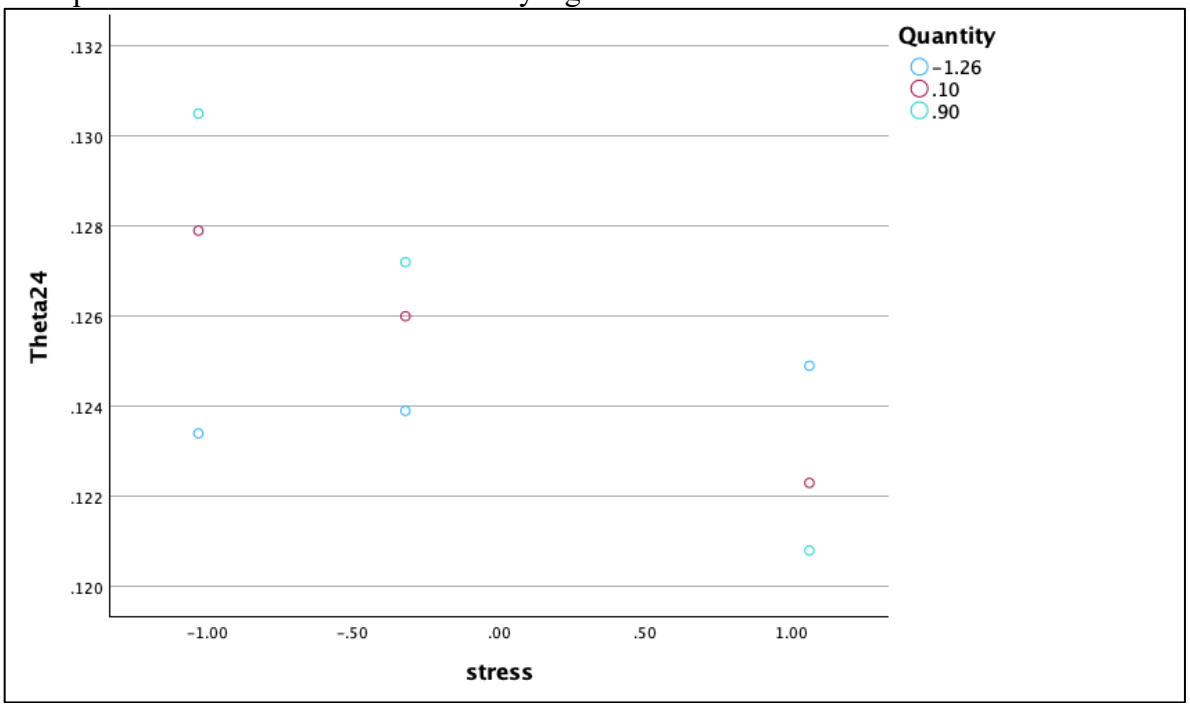

Figure B.7 – Model 6 moderation plot testing JA quantity as a moderator between stress and alpha power at 36 months. No statistically significant moderation observed.

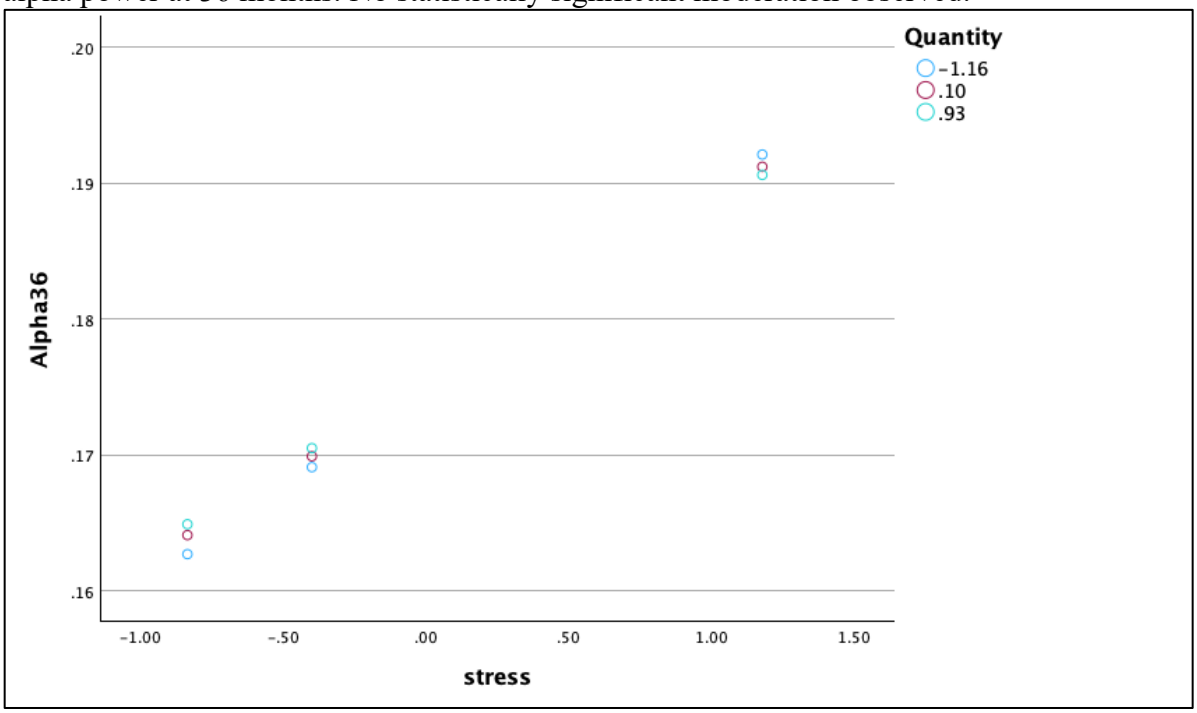

Figure B.8 – Model 8 moderation plot testing JA quantity as a moderator between stress and theta power at 36 months. A statistically significant moderation was observed.