THE ROLE OF HOUSEHOLD CHAOS AND MATERNAL MENTAL HEALTH IN INFANT SLEEP CONSOLIDATION

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Abstract

Developing healthy sleep hygiene in the early months of life is vital to an infant's physical, cognitive, and emotional development. Yet, there are many external and internal factors that contribute to infant sleep disturbances, thereby delaying the process by which infants learn to sleep or consolidate sleep. While research to date has examined the negative effects of household chaos and maternal mental health disorders on infant sleep, these studies primarily assessed these factors through surveys, parent interviews or reports. The purpose of this study was to better understand the influences of household chaos and maternal mental health on infant sleep consolidation through real-world, naturalistic data obtained from sensors worn by the infant. To understand these relationships, audio and actigraphy data from 13 mother-infant dyads (n = 13) were compiled to examine household chaos and infant sleep consolidation, respectively. Additionally, the dynamic nature of maternal mental health was assessed through Ecological Momentary Assessments (EMA) in which mothers reported on their negative affect six times a day and provided a holistic score of their symptoms of anxiety and depression once a day. Pearson's partial correlation tests were used to assess relationships between household chaos, maternal mental health, and their relation to infant sleep consolidation. Additionally, the relations between the objective measure of chaos derived from audio recordings and traditional questionnaire measures assessed by the Confusion, Hubbub, and Order Scale (CHAOS) were examined using Pearson's correlation tests. By understanding the possible effects of household chaos on infant sleep consolidation, families can be encouraged to adopt changes into the home environment that may better facilitate infant sleep. Moreover, improved treatment and support can be developed for mothers with mental health disorders, providing health benefits to both the mother and infant.

Key words: infant sleep consolidation, sleep hygiene, household chaos, maternal mental health, multimodal sensor data

Introduction

Infant sleep has significant links with long-term developmental outcomes. As such, it is important to understand how infants learn to sleep and factors that may compromise infant sleep quality. In the first few months of life, infant sleep is highly fragmented and variable. However, over time, all infants learn to consolidate their short segments of sleep into a cohesive nighttime sleep. This process, often referred to as sleep consolidation, is essential to an infant's physical, cognitive, and emotional development.

Sleep hygiene refers to external characteristics such as "a bedroom environment and daily routines that promote consistent, uninterrupted sleep" (Sleep Foundation, 2020b, para.2). All humans, including infants, can benefit from the establishment of sound sleep hygiene, as sleep is essential to proper development and functioning. For infants, sleep is particularly important for physical and cognitive growth and is positively associated with "memory, language, executive function, and overall cognitive development" (Tham et al., 2017, p.135). Additionally, a number of studies have found associations between infant sleep and physical outcomes such as weight gain and obesity (Gillman et al., 2008; Taveras et al., 2008). Evidently, quality sleep is crucial to all aspects of development. Thus, it is important to understand infant sleep consolidation and the factors that may hinder the establishment of proper sleep hygiene in infancy.

When considering how healthy sleep hygiene is established, the infant's surrounding environment plays a crucial role in sleep development and quality. Of the many factors that influence a home environment, household chaos is a salient feature to consider. Household chaos is characterized by the amount of noise, lack of routines and structure, and disorganization within a household. Indeed, studies have related the presence of excessive household chaos with adverse developmental outcomes in children and adolescents (Larsen & Jordan, 2019; Marsh, et

al., 2020). The impact of high household chaos has been shown to extend to infant sleep, leading to slower progression of sleep consolidation and the establishment of appropriate sleep hygiene (Whitesell et al., 2018).

In addition to household chaos, an important external factor to consider in the development of proper sleep hygiene in infancy is maternal mental health and mood. The presence of postpartum depression, depression, and anxiety is common in new mothers (Meany, 2018). Unfortunately, because symptoms of maternal mental health disorders vary greatly and may not show physical manifestations, maternal mental health disorders may often go unnoticed. This is cause for concern, as studies have shown links between maternal mental health disorders and declines in infant sleep quality (Armitage et al., 2009).

Prior research that has investigated the effects of household chaos and maternal mental health on infant sleep primarily used subjective measures to assess these factors. For example, household chaos is most often measured through surveys such as the Confusion, Hubbub, and Order Scale (CHAOS) or through interviews conducted by research assistants (Marsh et al., 2020; Whitesell et al., 2018). Similarly, infant sleep is often measured through parent report, such as sleep diaries or questionnaires (Mindell et al., 2016; Tetreault et al., 2016). While there is value in these subjective measures, they are prone to bias, which can skew the assessment of household chaos and infant sleep. Additionally, maternal mental health and mood is often measured via a one-time assessment through a survey, which may not provide representative information about a mother's mental health, as it can vary rapidly throughout the day. Therefore, there is a need for frequent, objective measurements of these factors to eliminate bias and understand the dynamic nature of mental health at a fine temporal scale.

The current advancement in sensing and mobile technologies provides a feasible solution to this problem. High-density, ecologically valid data can be collected from infants' environments through sensors to objectively measure factors such as household chaos, infant sleep, and maternal mental health and mood. The present research showcases this with the use of actigraphy and audio sensors that were used to assess infant sleep and household chaos, respectively. The Movisens actigraphy sensor measured infant's motion throughout the day and night, from which infant sleep was extracted. The LENA audio sensor worn by the infant in a vest recorded audio that occurred within the home environment, from which a measure of household chaos was extracted. Additionally, this study utilized Ecological Momentary Assessments (EMA) to understand changes in maternal mental health and mood that occur within and across days. Therefore, with the use of sensors to objectively assess infant sleep and household chaos and with frequent assessments of maternal mental health and mood, this study is unique in its examination of links between household chaos, maternal mental health, and infant sleep consolidation with naturalistic high-density data. Moreover, the use of sensors in the home environment to collect objective data on everyday life allows researchers to access high-risk, low-income target populations who may otherwise be unable to participate in lab research due to tight schedules, thereby making these populations more accessible.

The present study aims to understand the relationships between household chaos, maternal mental health, and infant sleep consolidation using objective measures extracted from raw sensor data. Moreover, this work aims to explore if the associations found by previous works using subjective measures differ when using new objective measures.

This thesis begins with a framework of infant sleep consolidation, household chaos, and maternal mental health, followed by a description of the methodology used to capture these

parameters with sensor data. Next, a description of the correlation analyses conducted for this project is provided. It is important to note that because correlation tests were performed as part of this study's analyses, conclusions of potential associations, and not causations, can be made from this work. While this thesis primarily uses objective measures to assess household chaos, a comparison of the data obtained from the sensors and CHAOS questionnaires is made in this thesis. This comparison of the objective versus subjective assessments of household chaos can provide insight into the validity of these measurements along with any limitations contained in these measures. By uncovering the potential associations between household chaos and maternal mental health on infant sleep, this thesis can provide insight about possible implications and best practices that facilitate an infant's development of sleep hygiene.

Infant Sleep Consolidation

Sleep is a process that is central to human life. Therefore, developing healthy sleep hygiene is essential to proper physical and cognitive development. Humans develop proper sleep hygiene in infancy, and over time, they begin to learn how to sleep in a process called infant sleep consolidation.

Infant sleep consolidation refers to the phenomenon by which infants gradually weave their sleep cycles into a cohesive unit and learn to sleep through the night. In the first two months of life, infants sleep in cycles or segments totaling an average of 14-17 hours per day and wake every few hours for feeding or other physiological needs (Sleep Foundation, 2020a). Within the first three to four months of life, infants experience the most dramatic changes in their sleep and wake cycles (Henderson et al., 2011). The most profound changes occur in the first two months, where the longest stretch of sleep per night for infants can increase from 3-4.5 hours to around 6

hours (Henderson et al., 2011). By 5-6 months of age, most infants develop typical sleep patterns, and their night sleep becomes longer and more regular, ranging from 7-9 hours per night (Mindell et al., 2016). This is a significant milestone in infancy, and it signals that sleep consolidation has occurred.

The factors that influence infant sleep consolidation can be physiological, psychological, or environmental, and sleep disturbances typically arise from a combination of these factors. Environmental factors, such as the amount of household chaos or the location of the sleep environment, can impact an infant's ability to consolidate sleep (Whitesell et al., 2018). While household chaos is composed of many factors within the home environment, it can be heavily influenced or driven by parent behaviors such as feeding schedules, household routines, and sleep structure. These behaviors demonstrate strong relationships to the quality of sleep an infant receives each night (Karraker, 2008). Studies that investigate parent/caregiver behaviors, particularly at bedtime, and infant and parent sleep often uncover the bidirectional associations that exist between parent/caregiver sleep and infant sleep (Karraker, 2008). For example, if a parent/caregiver behavior at bedtime yields increased infant night waking in a particular night, this could result in poor sleep for the parent/caregiver who must attend to the infant during the wake episodes. The disruption in sleep for both infants and the parent/caregiver can lead to increased infant distress and irritability or mood changes in the parent. As such, the physiological, psychological, and environmental factors that influence infant sleep consolidation are often intertwined and complex, and infant and parent behaviors may inadvertently reinforce each other.

From a psychological perspective, a mother's mental health can directly or indirectly impact infant sleep consolidation. Studies measuring the extent of major depressive disorder

(MDD) within mothers and infant sleep found that infants who have mothers with depressive disorders typically experienced more sleep disturbances throughout the night, which was characterized by an increased number of sleep episodes (Armitage et al., 2009). Additionally, sleep latency, or the amount of time it takes for an infant to fall asleep, was longer for infants with mothers who had depressive disorders (Armitage et al., 2009). Therefore, maternal mental health disorders are important to consider when investigating factors that may negatively impact infant sleep consolidation.

Evidently, infant sleep consolidation is complex and can be highly variable, when considering the many factors that can result in sleep disturbances. Developing a stronger understanding of the potential associations that a few of these factors can have on infant sleep consolidation can enable us to begin to minimize sleep disturbances in infancy, which is crucial to the development of proper sleep hygiene.

Household Chaos

The home environment that a child is reared in plays a multifaceted role in the child's development (Whitesell et al., 2018). A substantial factor to consider when examining children's home environments is household chaos. Household chaos refers to the extent of excessive noise or a lack of organization within a household, which is typically characterized by the absence of routines or structure in the home environment (Marsh et al., 2020). Households with high chaos typically display high disorder, an absence of routines, high levels of noise, and frequent disruptions. The amount of chaos within a household can vary by a multitude of factors including the number of members in the household or the socioeconomic status of the family (Marsh et al., 2020; Dumas et al., 2010). Typically, families of low socioeconomic backgrounds face many

added stressors to their daily lives, which can contribute to increasingly chaotic households (Evans et al., 2005). For example, it is possible that caregivers of lower socioeconomic households have less predictable work schedules, thereby making it difficult to establish structure and routines into the home environment. As such, families of lower socioeconomic backgrounds likely have higher household chaos but do not necessarily have the resources or means to add in structure. This is a significant cause for concern when considering child development, as children of lower socioeconomic backgrounds may be more subject to the negative physical and behavioral outcomes of high household chaos. Evidently, studying household chaos and its impact on children's physical, behavioral, and emotional development is necessary to understand potential areas of intervention and reduce the current disparities that result in children's outcomes because of chaotic home environments.

Additionally, more family members living within a household can make it increasingly challenging to establish household structure if each member has different schedules and responsibilities. However, the contributors to household chaos are not limited to these factors – the concept of household chaos is complex and requires the examination of the familial and ecological aspects of the home environment to obtain a holistic assessment. Nevertheless, the home environment is integral to an infant or child's development, and as such, studying household chaos can provide valuable insight into the quality of the home environment and its contributions to a child's developmental outcomes.

Implications of High Household Chaos

Prior research of home environments has found long-term adverse developmental outcomes for children in households with high chaos. Many studies have found that high household chaos is commonly associated with negative behavioral outcomes in adolescence. For

example, a study that investigated household chaos and child behaviors found that children who are raised in households with higher levels of chaos are more likely to exhibit externalizing behaviors such as aggression, outbursts, and bullying (Larsen & Jordan, 2019). Another broader review of the impacts of high household chaos found a range of adverse child and family outcomes ranging from lower quality parenting behaviors to increased inflammatory responses and lower quality sleep among children (Marsh et al., 2020).

The effects of high household chaos have also been linked to poor sleep outcomes and sleep disturbances. A study that examined the links between household chaos and adolescent sleep quality found that households with high chaos typically had family members engaging in "sleep-disturbing activities," such as watching TV, listening to music, or interacting with friends or relatives, and these activities were associated with lower sleep quality (Spilsbury et al., 2017). These previous studies suggest that high household chaos has widespread implications that can interfere with a child's normal physical, mental, and emotional development. Additionally, it is evident that that impacts of high household chaos can linger into adolescence and may continue to impact an individual's health and relationships into adulthood.

While many of the studies of the implications of household chaos to date focus on physical and behavioral outcomes in early childhood and adolescence, it is worthwhile to investigate the possible effects of high household chaos during infancy. One possible process that can be adversely impacted by high household chaos is infant sleep consolidation. A 2018 study by Whitesell et al. investigated these factors and found that chaos in the home environment was associated with increased sleep disturbances among infants, which led to lower sleep quality and delayed infant sleep consolidation. While the focus of this study by Whitesell et al. (2018) is similar to the current research presented in this thesis, there are fundamental differences that

make the present research novel and unique. The most significant difference is in the measures of household chaos. In the study conducted by Whitesell et al. (2018), household chaos was measured during home visits and phone interviews with families participating in the study. However, in the present study, household chaos was measured using audio data collected by the LENA sensor worn by the infant, which records all audio present around the infant. Collecting raw audio data through sensors provides an objective assessment of the real-life home environment, as it is not hindered by the presence of research assistants collecting measures. Moreover, assessing household chaos through audio data avoids reporting biases that are common to subjective assessments, such as questionnaires. Therefore, the present research adds to the knowledge obtained by Whitesell et al. (2018) in providing another avenue to assess levels of household chaos in the naturalistic home environment.

Common Measures of Household Chaos

The concept of household chaos encompasses a wide range of factors that contribute to disorganization, noise, and confusion within the home (Marsh et al., 2020). Therefore, the complexity of household chaos requires that unique styles of measurements are used to assess the multi-dimensional nature of the home environment. Household chaos can be measured in a variety of ways, from self-report measures to direct home observations. To date, most of the studies that consider household chaos utilize surveys such as the Confusion, Hubbub, and Order Scale (CHAOS) (Marsh et al., 2020). While many modified versions of the CHAOS questionnaire exist, they typically consist of true-false or scale-based questions or statements that ask the family about environmental aspects of their home such as noise levels, home traffic, and structure or routines. As such, in general, the CHAOS questionnaire successfully measures

aspects such as environmental confusion and family behaviors that contribute to chaotic home environments (Matheny et al., 1995).

While the CHAOS questionnaire is a widely-accepted measurement tool for household chaos in the field of development psychology, it relies on self-report measures conducted by the families, making it a largely subjective assessment. Therefore, it may be valuable to obtain a more objective assessment for household chaos through ground-truth (direct observation) data. The current study accomplishes this by using real-world data collected by audio sensors to assess household chaos. Additionally, this study utilizes responses from CHAOS questionnaires by families as a second assessment of household chaos. As a result, both objective and subjective measures of household chaos are available for analysis, which may provide a more complete picture of the home environment and levels of chaos experienced by the infant and family.

However, it is important to note that the sampling algorithm used in this study to find areas of high household chaos within the audio data was only run for one recorded day for each participant, and as such, it is possible that it did not provide a holistic representation of the household environment for each family. The CHAOS questionnaire, which provides a holistic, yet self-reported, assessment of household chaos is partly used to address this limitation. By examining both measures of household chaos, this study benefits from having ground-truth, naturalistic data of household chaos and a holistic representation of household chaos as viewed by the mother.

Maternal Mental Health and Mood

Mental health constitutes an individual's "emotional, psychological, and social well-being" (U.S. Department of Health & Human Services (HHS), 2020, para.1). Like physical

health, mental health can impact an individual's ability to complete tasks, engage with others, attend to their personal needs, and fulfill their roles in society (HHS, 2020). While mental health is pertinent to individuals of all age groups and societies, an important population to consider is mothers. Among mothers, mental health disorders such as depression and anxiety can make it difficult for mothers to provide care and emotional support to their children. As such, infants and children of mothers with mental health disorders may be at risk for developmental challenges associated with the effects of one or multiple maternal mental health disorders (Bernard-Bonnin et al., 2004).

Unfortunately, maternal mental health disorders are prevalent in society, and many mothers experience the debilitating effects of these disorders while simultaneously tackling parenthood. Current trends show that about 10% of pregnant women have a mental health disorder of some kind, and 13% of new mothers have a mental health disorder (World Health Organization (WHO), 2021). In most cases, the mental health disorder is depression (WHO, 2021). Many studies conducted on child outcomes for children who have mothers with depression have demonstrated the adverse behavioral consequences that may be linked to maternal depression. A meta-analysis of studies that examined the link between maternal depression and child behavioral outcomes found that generally, children of mothers with depression tend to exhibit more behavioral problems (Beck, 1999). However, the effects of maternal depression are not limited to behavioral outcomes. In a study that examined maternal depression and child body mass index (BMI), the results indicated that chronic depression in mothers has some association with child weight – children with mothers who have chronic depression are at higher risk of being overweight (Lampard et al., 2014).

While most studies to date focus primarily on depression, it is important to note that other mental health disorders, such as anxiety, can have significant implications for both mothers and children (Glasheen et al., 2009). One study found that prenatal maternal anxiety was linked with increased attention-deficit hyperactivity disorders, problem behaviors, and symptoms of anxiety among children (Van den Bergh & Marcoen, 2004). Postnatally, there have been links between maternal anxiety and physical symptoms such as colic and adverse psychological or behavioral outcomes (Glasheen et al., 2009). These studies illustrate that mothers have significant influences on their children's physical, emotional, and mental health, and mental health disorders may prevent a mother from providing emotionally-sound support to her child during development.

Despite the current trends that show an increase in maternal mental health disorders, especially after childbirth, maternal mental health and mental health in general is often overlooked in many healthcare systems globally (Engle, 2009). Additionally, while the presence of mental health disorders is universal and non-discriminatory, maternal mental health disorders are typically more prevalent among mothers of low and middle-income families (American Public Health Association (APHA), 2019). Maternal mental health disorders can also be exacerbated by social and environmental influences, such as poverty and racism (APHA, 2019). Yet, current public policy largely undermines the severity of mental illness, and as a result, healthcare providers and facilities are unequipped to adequately handle maternal mental health disorders and provide interventional resources to pregnant women and new mothers (APHA, 2019). This is a significant cause for concern when considering the associations that have been uncovered between maternal mental health and child development. To mitigate the negative effects of maternal mental health disorders on child development, changes need to be made on a

healthcare and public policy level (Engle, 2009). In healthcare, emphasis on mental health can be made by primary-care providers (PCPs), and resources can be allocated in a more efficient manner to allow PCPs to offer increased support and coping strategies for mothers with mental health disorders (Engle, 2009). On a public policy level, more current research should be integrated into healthcare policies that better reflect the pervasiveness and severity of mental health disorders among women (Engle, 2009). This can be achieved by policies that enable more affordable care and treatment for mental health disorders and better allocation of mental health resources among all populations.

When considering the patterns that emerge because of maternal mental health disorders during early infancy, it is important to understand that infant sleep and maternal sleep are largely influenced by each other. Actigraphy measurements of maternal and infant sleep during the first months of an infant's life have demonstrated that in the first few weeks after childbirth, mothers tend to experience circadian disruption, or a disturbance in the "biological clock" that governs physiological processes such as sleep (Thomas et al., 2014). Over time, mothers' circadian cycles begin to return to a more regulated state (Thomas et al., 2014). From birth, infants begin to develop circadian rhythmicity as they learn to distinguish between day and night in the first few months of life (Thomas et al., 2014). Gradually, mother and infant sleep cycles begin to show correlations in a process called circadian dyadic synchrony (Thomas et al., 2014). The development of synchronous circadian cycles suggests that the bidirectional nature of infant and mother sleep is not only a behavioral process but also contains underlying physiological mechanisms.

Given that research to date has found links between maternal mental health disorders and challenges in children's physical and mental development, it is important to consider the

potential effects of maternal mental health in infant sleep consolidation. While infant sleep can be impacted by a variety of physical, social, and environmental influences, it is possible that maternal mental health may play a significant role in guiding some of these influences. A stronger understanding of the impact of maternal mental health on infant sleep consolidation, if any, could encourage healthcare providers to establish greater focus on mental health when caring for pregnant women and new mothers. Moreover, a greater emphasis on mental health during pregnancy and early infancy can encourage mothers to adopt coping strategies that support sound mental health and remove any intimidation in seeking mental health support when needed.

Implications of Maternal Mental Health Disorders

Maternal mental health disorders can have a large range of effects, often interfering with a mother's ability to attend to her physical and emotional needs (WHO, 2021). In some cases, the disruption caused by a mental health disorder may also hinder a mother's ability to properly tend to her child's needs. The level of impact that maternal mental health disorders have on child development is influenced by the severity and duration of the disorder (Lovejoy et al., 2000). Because of the prevalence of postpartum depression, the adverse effects of maternal mental health disorders on child health outcomes can begin as early as infancy (Bernard-Bonnin et al., 2004). During infancy, the interactions between a mother and infant greatly influence the infant's affect, ability to self-regulate, and sleep quality, among other physiological and emotional processes. The quality of a mother's interaction with her infant can be influenced by her mental health. The effects of mental health are particularly salient during infant bedtime, thereby influencing infant sleep consolidation (Lovejoy et al., 2000; Kim & Teti, 2013). For example, a study that investigated the influence of maternal depression on infant sleep found that infants

with mothers who had depressive disorders had an increased number of sleep episodes during the night (Armitage et al., 2009). The increased sleep episodes suggest an association between maternal depressive symptoms and sleep disturbances, indicating that maternal depression may play a role in hindering infant sleep consolidation. A similar finding emerged from another study which found that a mother's depressive symptoms were linked with infant night wakings, thereby following a "mother-driven model" in which the mother's behaviors more heavily influence infant sleep quality (Teti & Brian, 2012).

This idea is further supported in a study that examined the effects of symptoms of both depression and anxiety on infant sleep quality (Martini et al., 2017). The study found that excessive crying was more prevalent among infants with mothers who had anxiety disorders, whereas sleep disturbances were more common among infants with mothers who had depressive disorders (Martini et al., 2017). This study not only reiterates the influence that maternal mental health has on infant sleep quality, but also demonstrates that the manifestation of different mental health disorders may result in distinct infant outcomes. These studies also suggest that there are fundamental changes that occur to the quality of mother-infant interactions because of maternal mental health disorders and ultimately, the effects of lower quality interactions have the potential to interrupt infant sleep consolidation. However, it is important to note that the quality of mother-infant interactions cannot solely be attributed to maternal mental health, and a mother's emotional availability towards her infant may be influenced by her mental health but is susceptible to other environmental influences (Kim & Teti, 2013).

The negative impact of maternal mental health disorders on mother-infant interactions can result in delays in infant sleep consolidation. As such, the present study examines potential

associations between maternal mental health and infant sleep consolidation while accounting for the day-to-day variability in the symptoms of mental health disorders and maternal mood.

Hypotheses

We examined household chaos through both an objective measure from audio data and a subjective survey measure. The preliminary analysis in this study compared the two different measures of household chaos: the objective number of hours of high household chaos extracted from the audio data versus the self-reported survey measure obtained from the CHAOS questionnaire. This exploratory analysis was conducted using a Pearson's correlation test to determine the relationship between the objective and subjective measures of household chaos.

Next, the current study examined the relationships between household chaos, maternal mental health, and infant sleep consolidation using Pearson's partial correlation tests to control for infant age. Based on previous studies that have found adverse effects of household chaos on infant sleep quality, we hypothesized that high household chaos would be associated with delays in infant sleep consolidation. This would present itself in two ways: a positive correlation between the number of hours of high household chaos (normalized) and the average number of infant wake episodes (Hypothesis 1) and a negative correlation between the number of hours of high household chaos (normalized) and the infant's average longest stretch of sleep (Hypothesis 2).

Additionally, because studies have found relationships between maternal mental health disorders and lower infant sleep quality, we hypothesized that higher scores of maternal depression, anxiety, and negative affect would be associated with delays in infant sleep consolidation. That is, we expected that average maternal depression scores would have a

positive correlation with the average number of infant wake episodes (Hypothesis 3) and a negative correlation with the infant's average longest stretch of sleep (Hypothesis 4). Similarly, we hypothesized that average maternal anxiety scores would be positively correlated with the average number of infant wake episodes (Hypothesis 5) and negatively correlated with the infant's average longest stretch of sleep (Hypothesis 6). Lastly, we expected similar results for maternal negative affect in that maternal negative affect scores would have a positive correlation with the average number of infant wake episodes (Hypothesis 7) and a negative correlation with the infant's average longest stretch of sleep (Hypothesis 8).

Methodology

Dataset

Data for this study was compiled from the de Barbaro K01 dataset, which includes a total of 87 participants. The mean infant age was 4.46 months (SD = 2.46 months, Range = 0.87-10.8 months), and the mean mother age was 31.18 years (SD = 5.67 years, Range = 19-42 years). Of the 87 participants, 20 were from low socioeconomic backgrounds (family annual income under $25,000-$49,999), 31 were from middle socioeconomic backgrounds (family annual income $50,000-$99,999), and 32 were from high socioeconomic backgrounds (family annual income above $100,000). Data on annual family income was not provided by 4 participants. Participants were recruited through flyers placed on campus, social media, and the CommuUnity Care Clinic in Austin, Texas. Most of the participants resided in the Austin area and were from English- or Spanish-speaking families.

Participant Selection

For the current study, we used a subset of 13 participants from the main K01 dataset. Participants were chosen based on the following criteria:

1. Infants were between 0-9 months of age.
2. Participants were from English-speaking families.
3. Information on family annual income was available. Participants were controlled for socioeconomic status (SES) based on their annual family income giving an almost even distribution (3 low SES, 5 mid SES, 5 high SES).
4. Over 12 hours of continuous recordings from the LENA audio sensor were available.
5. The raw audio recorded by LENA was annotated for high household chaos by trained research assistants from the Daily Activity Lab.
6. The wearer compliance for the Movisens actigraphy sensor was over 60% for infant night sleep (nighttime was considered from 5pm to 10am the next morning).
7. Measures of maternal depression, anxiety, and negative affect from Ecological Momentary Assessments (EMA) were available for each mother.

Audio Data

Audio recordings were collected through the LENA audio sensor worn by the infant in a vest. LENA devices are capable of recording audio sounds within a ten-feet distance of the wearer. The audio recorded by LENA was used to extract a measure of auditory household chaos and other environmental noises surrounding the infant. On average, about 72 hours of audio is recorded per participant, which is split across weekdays and weekends. The audio recorded per day is continuous and time stamped. Across the 87 participants, a total of 4,597 hours of raw audio data has been collected using LENA to date. In this study, the audio data was used to create an objective measure of household chaos for each participant.

Infant Actigraphy Data

Actigraphy is a measurement of human activity and sleep/rest through motion detection and heart-rate monitoring. The actigraphy sensor used in this study was the Movisens, which is a sensor that collects the movement data, acceleration, and heart rate of the wearer. In this study, the Movisens was worn by both the mother and infant and was attached to their bodies through adhesive pads, much like the adhesive technology used for electrocardiograms (ECGs). Infant data from the Movisens was used to compute the amount of wake episodes and length of sleep episodes for each infant per night, which were used as measurements of infant sleep consolidation.

Household Chaos Survey Measure

Prior research has measured household chaos through the Confusion, Hubbub, and Order Scale (CHAOS) questionnaire or through interviews in the family home. The CHAOS questionnaire is widely accepted in the field of developmental psychology. In this study, the CHAOS questionnaire served as a comparison for the naturalistic household chaos measured by the LENA sensor. For 7 of the 13 participants included in this study, a subjective, mother-reported measure of household chaos was obtained through the CHAOS questionnaire.

The CHAOS questionnaire is a self-reported measure of household chaos completed by the mother during the data collection process. The questionnaire asks varying questions to characterize the amount of chaos within the household, including questions referring to noise levels and sound, which were also measured by the LENA device. Other questions ask about the extent of routines within the household and the home atmosphere. Each question was scored on a scale from 1 to 4, with 1 representing that the statement was “very much like your own home” and 4 representing that the statement was “not at all like your home.”

Ecological Momentary Assessments (EMA)

To understand and account for the potential impact of household chaos or other stressors in a given day on maternal mental health, Ecological Momentary Assessments (EMA) were used to assess the mothers' symptoms of depression, anxiety, and negative affect. The EMA is a tool used in psychology and behavioral medicine to understand changes that occur in behavior and cognition throughout the day within an individual's natural environment (Smyth & Stone, 2003). EMAs are particularly useful in taking repeated measurements so that changes in behaviors and thoughts maybe tracked and understood (Smyth & Stone, 2003). As such, EMAs can provide valuable insight into rapidly changing or evolving human processes such as mood, affect, and pain (Smyth & Stone, 2003).

The Daily Activity Lab's study participants are given EMAs six times per day via text messages. All six EMAs that are sent per day ask questions about the mother's mood by prompting her to rate qualities of both positive and negative affect on a scale from 1 to 5 (1 = lowest; 5 = highest). Qualities of positive affect included "enthusiastic," "energetic," "satisfied," and "happy," and qualities of negative affected included "tense," "anxious," "guilty," and "irritable." Additionally, once a day, mothers were asked questions about their depression and anxiety symptoms. In this study, participant responses of depression symptoms, anxiety symptoms, and negative affect were used to assess maternal mental health and mood.

Data Processing

Household Chaos

To explore the effects of high household chaos on infant sleep, it is important to obtain a measure of high household chaos. In this study, we used three measures of household chaos. Two of these measures were extracted from the audio data collected by the LENA sensor. The

first measure was the *automatically-detected high chaos*, which was extracted by a high chaos sampling algorithm developed by the Daily Activity Lab. The second measure, *human-annotated high chaos*, was obtained by validating the automatically-detected high chaos by trained research assistants who checked if each automatically-detected high chaos audio segment truly contained high chaos. Therefore, the human-annotated high chaos measure is a validated subset of the automatically-detected high chaos measure, and the *human-annotated high chaos measure* is the objective measure of household chaos used in this study's analyses.

The third measure of household chaos is the *self-reported household chaos measure* obtained from the CHAOS questionnaires. The self-reported measure was used to generate two totals: a "self-reported CHAOS Total Score," which is a sum of all the items on the CHAOS questionnaire, and a "self-reported CHAOS Auditory Score," which is a sum of only the items of the CHAOS questionnaire which assess the auditory components of the home environment.

Human-Annotated High Chaos Measure

It is infeasible to hand-annotate high chaos within 12-24 hour-long recordings per participant to extract information on the number of high chaos hours per day and obtain an objective measure of household chaos. Therefore, a system that can automatically process entire audio recordings and extract the number of high chaos hours per day was required. An automated audio processing approach was used to achieve this measure. The high chaos sampling algorithm developed by the Daily Activity Lab was used to automatically sample audio segments (each 5 seconds in length) where there is a high likelihood of high chaos from each audio recording. This was done by extracting and processing the acoustic information present in the audio. These *automatically-detected high chaos* segments were further validated by trained research assistants to check if high chaos was truly present within these sections of the audio. These human-

annotated high chaos audio segments were then summed up to calculate the number of hours of high chaos in each audio recording to generate the *human-annotated high chaos measure.*

The performance of the high chaos sampling filter was assessed to ensure it captured most areas of high chaos within the audio recordings. To do this, the performance of the high chaos sampling filter was compared against random sampling of high chaos sections. The sampling algorithm selected segments that it considered to be high chaos from 3 participants' day-long recordings. The same number of segments chosen by the sampling algorithm from each participant were also randomly sampled from the same participants. Both set of audio segments were given to the research assistants to be validated for high chaos. A comparison between the randomly sampled segments and the segments selected by the sampling algorithm showed that the segments selected by the sampling algorithm contained nine times more high chaos segments on average than the randomly sampled segments. This indicates that the household chaos algorithm successfully selects areas of high household chaos within the audio files and can be used to measure the number of hours of high household chaos in a given day for each participant.

To get the human-annotated high chaos measure, four research assistants were trained over 6-8 months and achieved a kappa score of $k = 0.76$ for inter-coder reliability, indicating strong agreement between the research assistants' assessments of household chaos. This methodology of hand-annotating only the automatically-detected high chaos measure minimized the hand-annotation effort for entire day-long recordings to only a few hours per participant, which was a huge advantage. Collectively, audio segments selected by the sampling algorithm across 13 participants were annotated over 6 months by research assistants. However, because there were differing amounts of audio data available for each participant, it is likely that a higher number of hours of high household chaos would be predicted for longer recordings. For example,

more high household chaos would likely be found in 24 hours of audio data versus 12 hours of audio data. Therefore, prior to being used in the analyses, the human-annotated high chaos measure was normalized to represent 24 hours for each participant to ensure that the length of the audio recording did not influence the high household chaos hours assessed for the participants. Normalization of the high household chaos hours was achieved by the following calculation: (24/Total Length of Recording) * (Hours of Human-Annotated High Chaos).

Self-Reported Household Chaos Measure

The CHAOS questionnaires completed by the mothers were scored to find a self-reported household chaos measure. Due to the wording of the statements, a score of 1 or 4 for each statement on the CHAOS questionnaire did not necessarily correspond to high or low chaos, so a method of reverse-coding was applied to some of the questions when scoring the questionnaires. With this method, the scores given by the participants for some of the statements were reversed (4 became 1, 3 became 2, and so on), and a total CHAOS score was calculated after reverse-coding to generate a "self-reported CHAOS Total Score." Self-reported CHAOS Total Scores ranged from 16-60, and a *low* self-reported CHAOS Total Score corresponded to *high* household chaos, whereas a *high* self-reported CHAOS Total Score corresponded to *low* household chaos.

The LENA sensor primarily evaluates auditory household chaos while the CHAOS questionnaire measures auditory aspects of household chaos along with household structure and routines. Because of these differences, a second total from the questionnaire was calculated to only include responses from questions that assessed the sounds or noise in the home environment. Some of the statements from these survey items included "There is very little commotion in our home" and "It's a real zoo in our home." Responses from the survey items that assessed auditory components of household chaos were summed to generate a new auditory total,

"self-reported CHAOS Auditory Score," and correlations between the self-reported CHAOS Auditory Score and the human-annotated high chaos measure were assessed.

Extracting Infant Sleep from Actigraphy Data

Infant sleep episodes were computed using a pre-existing algorithm commonly used in sleep research, the Sadeh algorithm. Output from this algorithm included the number of infant wake episodes each night and the infant's longest stretch of sleep each night (minutes). Because there are many factors that contribute to the quality and quantity of infant sleep each night, using infant sleep data from one night would likely not be an accurate representation of the infant's sleep consolidation. Therefore, to obtain a more thorough assessment of infant sleep consolidation, these infant sleep measurements were averaged across all nights (5pm-10am) that the Movisens wearer compliance was over 60%, so that an average value of infant wake episodes and infant's longest stretch of sleep was calculated for each infant.

Assessing Maternal Mental Health and Negative Affect with EMAs

Like infant sleep, assessing a mother's depression, anxiety, and negative affect on one day may not be representative of her overall mental health and mood. Therefore, an average of the mother's negative affect, depression, and anxiety symptoms assessed by the EMAs was calculated across all the days the mother completed the EMAs as a representation of maternal mental health and mood for the study. The scores for negative affect, depression, and anxiety were used in the analyses to determine associations between maternal mental health and infant sleep consolidation.

Outlier Removal

To increase the power of the statistical analyses, outliers within any of the parameters were removed from the compiled dataset. For the purposes of this study, an outlier was any value

that was above or below 2.5 standard deviations from each measure's mean. Based on this consideration, one outlier was identified and removed from the human-annotated high chaos hours before the statistical analysis was performed. All other parameters did not contain any outliers, so the complete compiled dataset was used for the remaining analyses.

Analyses

First, the possible relationships between the subjective survey measure of household chaos and the objective human-annotated high chaos measure extracted from the audio data were examined through a Pearson's correlation test. Next, the potential relationships between household chaos and infant sleep consolidation and maternal mental health and infant sleep consolidation were examined through correlation tests. However, because infant ages ranged from 0-9 months, it was important to control for age-related associations that could possibly affect infant sleep. Therefore, Pearson's partial correlation tests were used to control for infant age, and tests were run to assess the relationships between all sleep outcome variables and household chaos and maternal mental health predictors.

Results

Descriptive Analyses of Parameters

Prior to conducting the Pearson's partial correlation tests, a descriptive analysis of all the parameters used in this study was calculated. Table 1 contains a summary of the descriptive statistics.

Table 1. Summary of means and standard deviations of all measurements included in the analyses.

	Mean	**Standard Deviation**
Infant Age (months)	3.826	1.895

Human-Annotated High Household Chaos Hours (normalized)	0.370	0.442
Self-Reported CHAOS Total Score	46.5	10.043
Self-Reported CHAOS Auditory Score	27.625	6.545
Maternal Depression Score	0.347	0.392
Maternal Anxiety Score	0.539	0.495
Maternal Negative Affect Score	2.291	1.006
Average Number of Infant Wake Episodes	10.608	3.005
Infant's Average Longest Stretch of Sleep (minutes)	217.402	86.869

Comparison of Subjective Self-Reported Household Chaos Measure Versus Objective Human-Annotated High Chaos Measure

Pearson's correlation tests assessed the relationship between the "self-reported CHAOS Total Score" and the human-annotated high chaos measure extracted from the audio collected by the LENA sensor. There was an insignificant relationship between these two measures of household chaos ($p > 0.05$). Additionally, a Pearson's correlation test was used to assess the relationship between the sum of the auditory components of the CHAOS questionnaire ("self-reported CHAOS Auditory Score") and the human-annotated high chaos measure, which also showed an insignificant relationship ($p > 0.05$). As such, we used the objective measure of human-annotated high chaos extracted from the audio data for the following analyses, given that an objective measure is free of biases and more representative of the infants' naturalistic home environments.

Table 2. Summary of Pearson's correlation test outputs for the comparative analysis between subjective measures of household chaos and objective measures of auditory household chaos.

Associations between the objective measures and subjective measures of household chaos.	
	CHAOS Questionnaire Totals

	Self-Reported CHAOS Total Score		Self-Reported CHAOS Auditory Score	
	r-value	p-value	r-value	p-value
Human-Annotated High Chaos Hours (normalized)	0.060	0.887	0.010	0.978

Household Chaos and Infant Sleep Consolidation

Hypothesis 1: Human-annotated high chaos hours and average number of infant wake episodes.

Pearson's partial correlation tests showed no significant correlations between the human-annotated high chaos measure and average infant wake episodes ($p > 0.05$). Partial correlation test results are depicted in Figure 1.

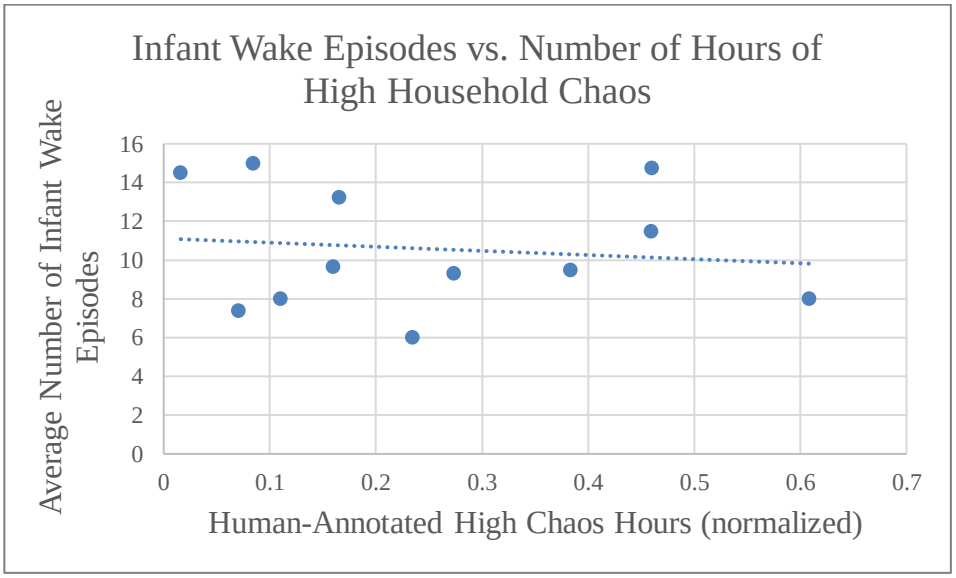

Figure 1. Correlation between the objective human-annotated high chaos measure and infant's average wake episodes.

Hypothesis 2: Human-annotated high chaos hours and infant's average longest stretch of sleep.

No significant correlations were found between the human-annotated high chaos measure and the infant's average longest stretch of sleep in minutes ($p > 0.05$) based on the Pearson's partial correlation test. Partial correlation test results are depicted in Figure 2.

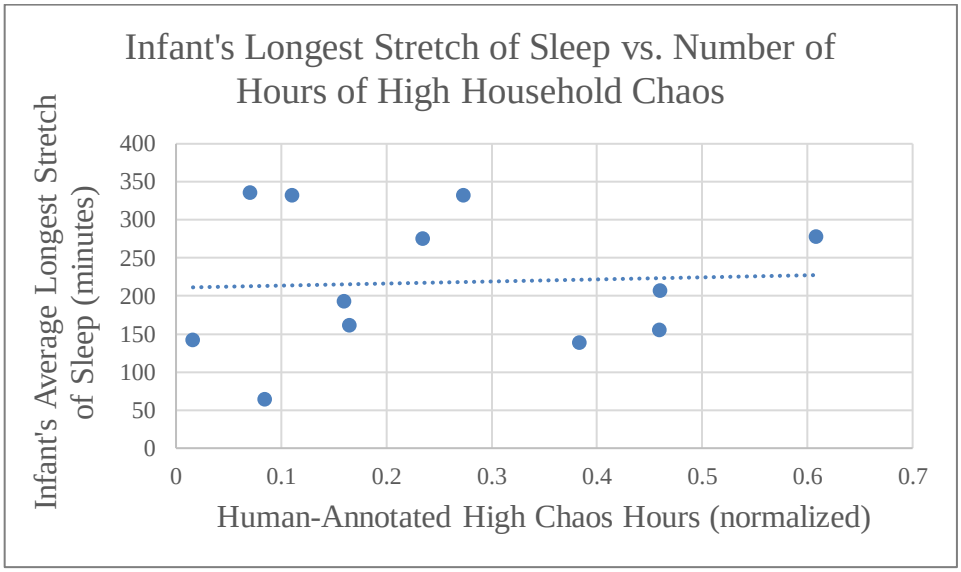

Figure 2. Correlation between the objective human-annotated high chaos measure and infant's average longest stretch of sleep.

Maternal Mental Health and Infant Sleep Consolidation

Hypothesis 3: Maternal depression and average number of infant wake episodes.

No significant correlations were found between maternal depression and average infant wake episodes ($p > 0.05$) based on the Pearson's partial correlation test. The correlation between maternal depression and average infant wake episodes is depicted in Figure 3.

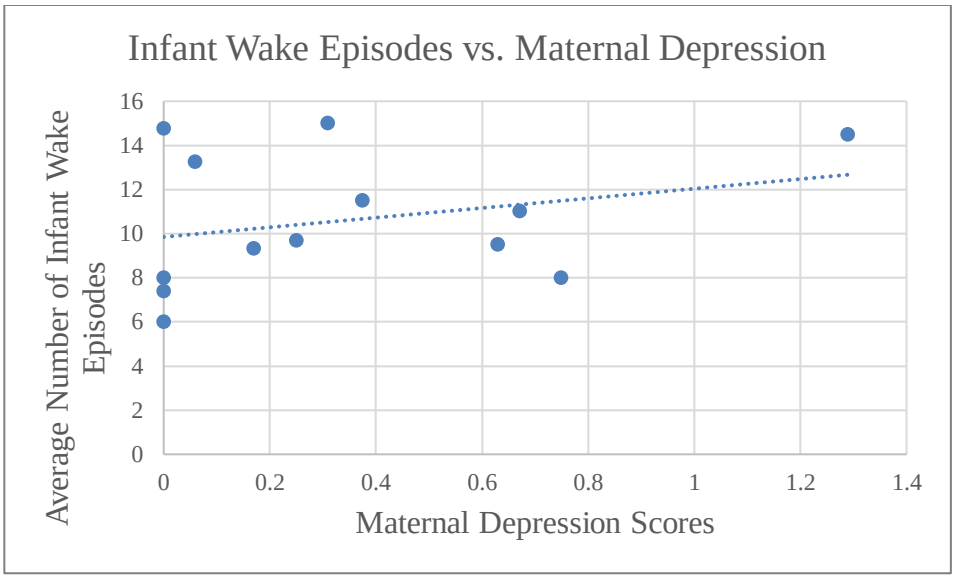

Figure 3. Correlation between maternal depression scores and the average number of infant wake episodes.

Hypothesis 4: Maternal depression and infant's average longest stretch of sleep.

According to the results of the Pearson's partial correlation test, maternal depression and infant's longest stretch of sleep did not appear to be significantly related ($p > 0.05$). The results of this correlation test are depicted in Figure 4.

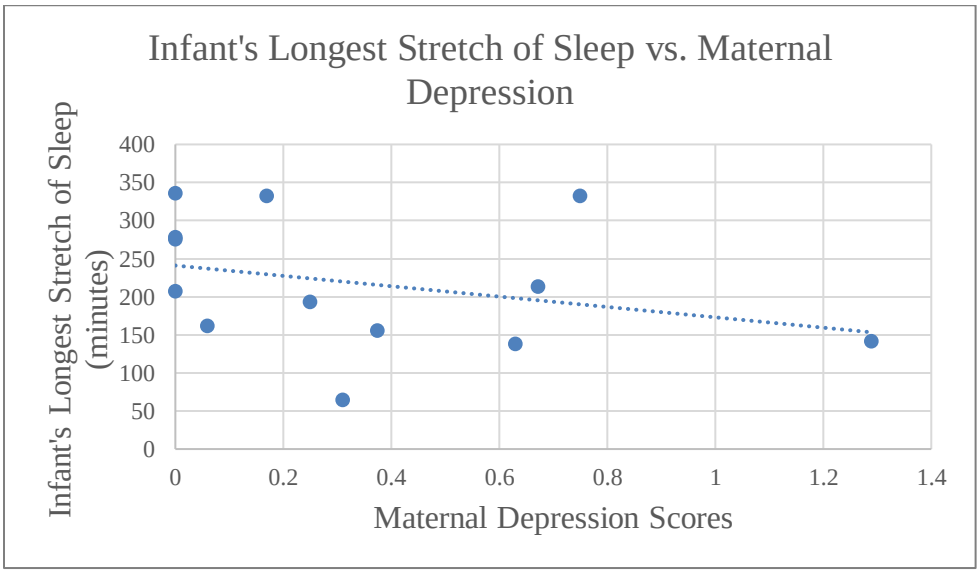

Figure 4. Correlation between maternal depression scores and the infant's average longest stretch of sleep (minutes).

Hypothesis 5: Maternal anxiety and average number of infant wake episodes.

No significant correlations were found between maternal anxiety and average infant wake episodes ($p > 0.05$) by the Pearson's partial correlation test. The correlation between maternal anxiety and average infant wake episodes is shown in Figure 5.

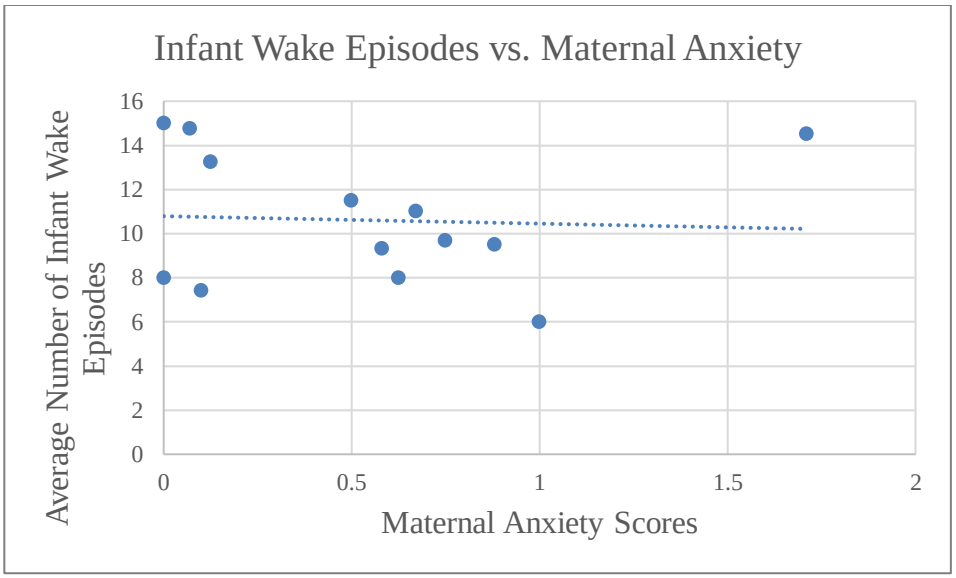

Figure 5. Correlation between maternal anxiety scores and the average number of infant wake episodes.

Hypothesis 6: Maternal anxiety and infant's average longest stretch of sleep.

Pearson's partial correlation test indicates that there is no significant relationship between maternal anxiety and infant's average longest stretch of sleep ($p > 0.05$). Partial correlation test results are shown in Figure 6.

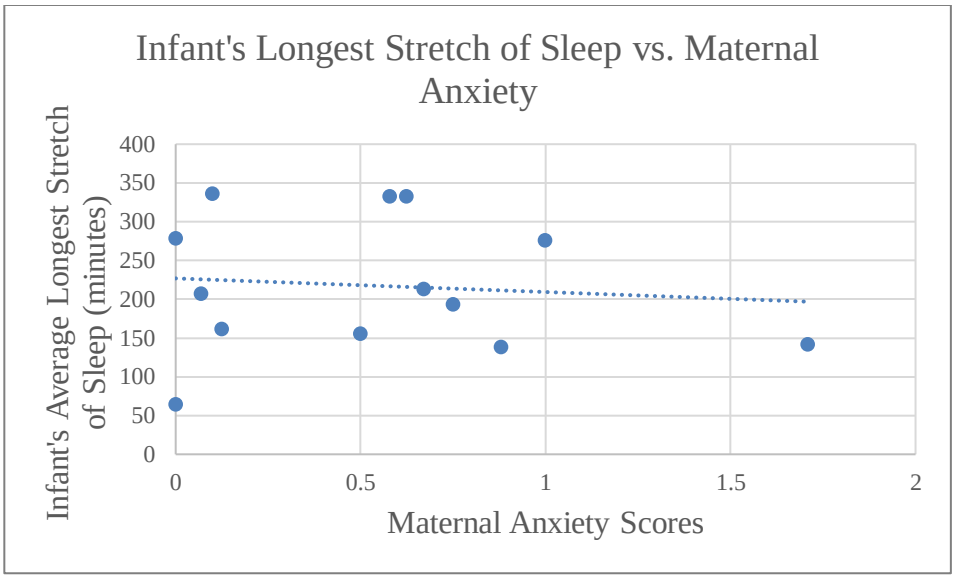

Figure 6. Correlation between maternal anxiety scores and the infant's average longest stretch of sleep (minutes).

Maternal Negative Affect and Infant Sleep Consolidation

Hypothesis 7: Maternal negative affect and average number of infant wake episodes.

No significant correlations were found between maternal negative affect and the average number of infant wake episodes by the Pearson's partial correlation test ($p > 0.05$). The correlation between maternal negative affect and average number of infant wake episodes is depicted in Figure 7.

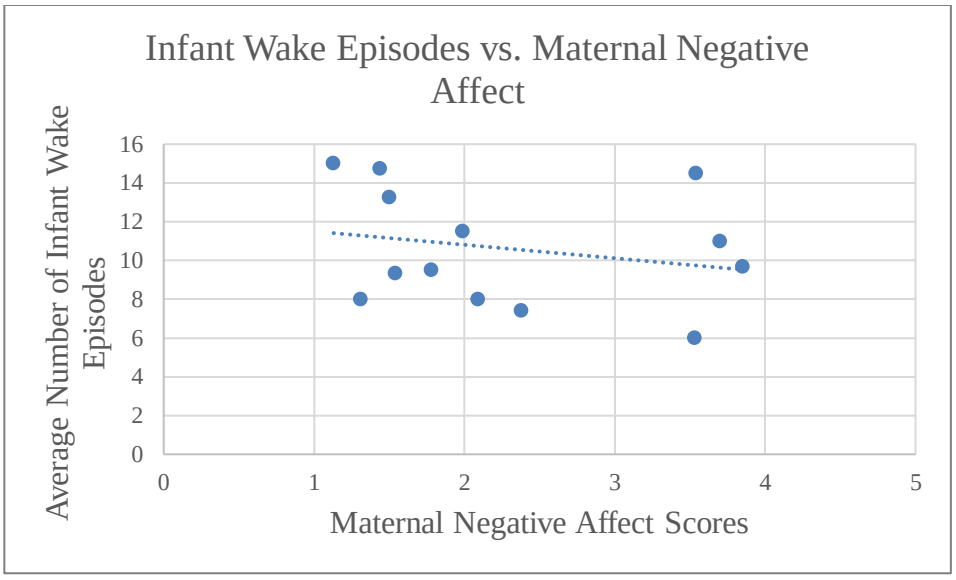

Figure 7. Correlation between maternal negative affect scores and the average number of infant wake episodes.

Hypothesis 8: Maternal negative affect and infant's average longest stretch of sleep.

According to the results of the Pearson's partial correlation test, maternal negative affect and infant's average longest stretch of sleep did not appear to be significantly related ($p > 0.05$). The results of this partial correlation test are shown in Figure 8.

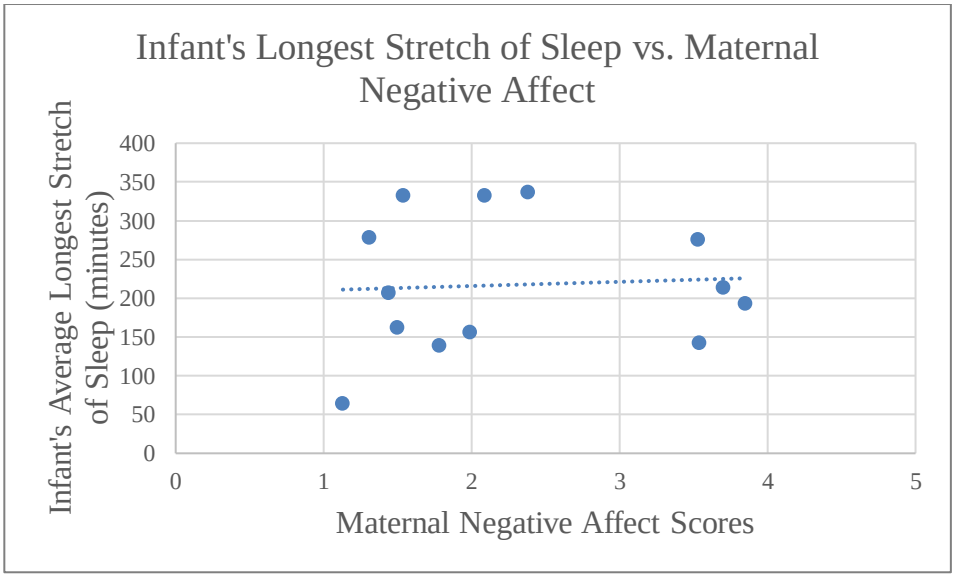

Figure 8. Correlation between maternal negative affect scores and infant's average longest stretch of sleep (minutes).

A summary of the results of all partial correlation tests included in this study is depicted below in Table 3.

Table 3. Summary of Pearson's partial correlation test outputs. All outputs showed insignificant associations between household chaos, maternal mental health, maternal negative affect, and measures of infant sleep consolidation ($p > 0.05$).

Associations between high chaos, maternal mental health, and maternal negative affect and infant sleep consolidation measures.

	Infant Sleep Consolidation			
	Infant's Average Number of Wake Episodes		Infant's Average Longest Stretch of Sleep (minutes)	
	r-value	p-value	r-value	p-value
Human-Annotated High Chaos Measure (normalized)	-0.126	0.712	0.051	0.881
Maternal Depression	0.283	0.371	-0.301	0.342
Maternal Anxiety	-0.107	0.741	-0.081	0.802
Maternal Negative Affect	-0.264	0.407	0.068	0.833

Discussion

In a sample of 13 participants, we examined the potential associations that household chaos and maternal mental health and mood can have on infant sleep consolidation. Our hypothesis was that increased household chaos would result in delays in infant sleep consolidation, which would present as an increased average number of infant wake episodes or decreased average longest stretch of sleep. However, a significant relationship between the objective human-annotated high chaos measure and infant sleep consolidation was not found, suggesting that there is no significant correlation between household chaos and infant sleep consolidation while controlling for infant age. This could indicate that high household chaos in a day does not have as substantial of an effect on infant night sleep as hypothesized. Instead, there may be other environmental or internal influences that may have a more potent effect on infant

sleep. For example, intrinsic, physiological factors, such as circadian rhythmicity and infant health conditions could more significantly govern infant sleep. Additionally, because the naturalistic measure mostly encompassed auditory household chaos, it is possible that other characteristics of household chaos, such as lack of structure or routines, may have a more pertinent influence on infant sleep consolidation (Whitesell et al., 2018).

Due to numerous previous studies that have found associations between maternal depression and anxiety and decreased infant sleep quality, we hypothesized that higher average scores of both depression and anxiety would result in delays in infant sleep consolidation, i.e. increased number of average wake episodes and decreased average longest stretch of sleep among infants. However, the partial correlation tests assessing these relationships indicate that there is no association between maternal depression and anxiety and infant sleep consolidation while controlling for infant age. Additionally, maternal negative affect did not appear to be associated with infant sleep consolidation. While this may suggest that maternal mental health and mood do not have a significant effect on infant sleep consolidation, this finding may also be explained by the method by which the EMAs were scored. Previous studies that have investigated the role of maternal mental health on infant sleep quality have found that the possible implications of maternal mental health disorders are particularly salient at infant bedtime. For the purposes of this study, the mothers were given EMAs to complete throughout the day, and their scores for depression, anxiety, and negative affect were averaged within and across days. It is possible that focusing on maternal mental health and mood at infant bedtime could yield significant associations with infant sleep consolidation, and therefore, should be emphasized in future studies.

In a separate analysis, we performed correlation tests to examine the potential associations between the subjective survey measures of household chaos obtained from the CHAOS questionnaires and the objective human-annotated high chaos measure extracted from the audio collected via the LENA sensor. We found no significant overlap between these measures of household chaos. Additionally, a follow-up correlation test using the self-reported CHAOS Auditory Score and the human-annotated high chaos measure did not show any significant associations between the two measures of household chaos. The lack of overlap between the subjective and objective measures of household chaos can be explained by several factors. Firstly, the CHAOS questionnaires were completed by mothers and therefore, were subject to report biases that may have hindered a representative assessment of the families' household chaos. Because the audio data assesses household chaos objectively, the insignificant associations between the two measures suggests that bias may be present in the subjective assessments, thereby misrepresenting the amount of chaos within the home environment. However, there are also aspects of the audio data's annotation method that may have contributed to the differences seen between the objective and subjective measurements of household chaos. For example, when annotating segments for chaos, the research assistants considered infant sounds such as vocalizations, fusses, and cries as contributing noises to household chaos. It is likely that when the mothers completed the CHAOS questionnaires, they did not consider infant sounds when answering questions that related to the amount of noise within the home environment. Additionally, research assistants considered features such as female and male speech and its volume and noises external to the home environment, such as traffic sounds. However, it is probable that when mothers answer the questions on the CHAOS questionnaire, they do not consider the contributions of speech and external environmental noises to household

chaos. In future studies where audio data is used to assess household chaos, it is important to consider the perspective of the study participants. For example, when assessing household chaos from the infant's perspective, areas in the audio that contain high infant sounds can be removed from consideration of household chaos. On the other hand, if household chaos is being assessed from the parent's perspective, it would be important to include infant sounds as a contributing factor to household chaos. An advantage to using objective measures of household chaos from audio data is that perspective can easily be considered, and specific target sounds can be included or subtracted from the assessment of household chaos to achieve a more representative measure.

This study primarily investigated the effects of two external factors – household chaos and maternal mental health – on infant sleep consolidation and found that there were no significant associations. While follow-up studies with a larger sample size is needed to truly understand the potential effects of these two external factors, the absence of significant relationships could suggest that there are other internal or external factors that play a more sizeable role in infant sleep consolidation. Nevertheless, a better understanding of the potential effects of high household chaos and maternal mental health disorders on infant sleep consolidation could be achieved through changes in the study design to encompass a larger population and long-term data.

Strengths, Limitations, and Future Work

Most studies that have investigated the associations between infant sleep, household chaos, and maternal mental health have explored these constructs through subjective measures such as surveys, questionnaires, or interviews. While there is value in obtaining participant-reported measures of these factors, there is risk for bias in subjective assessments. The primary strength of this study is the use of audio and actigraphy sensors to assess household chaos and

infant sleep consolidation, respectively. Through raw sensor data, objective assessments of these variables were obtained, thereby eliminating the presence of bias that may be found in parent-report measures and surveys/questionnaires. Additionally, through measurements from sensors, data could be obtained without the presence of a research assistant in the family home, and therefore, a naturalistic depiction of household chaos and infant sleep consolidation was achieved.

Studies in the past have evaluated maternal mental health disorders such as depression and anxiety with one-time surveys completed by the mother. While many of these surveys provide holistic assessments of the variety of symptoms presented from mental health disorders, they do not address the dynamic nature of mental health disorders. A strength of this study is the use of Ecological Momentary Assessments (EMA) to assess maternal mental health and mood. Mothers were asked to complete this survey multiple times in a day, and data across all the days was averaged to compute an average depression, anxiety, and negative affect score. Through EMAs, the day-to-day changes in maternal mental health and mood were assessed and included in the analysis of potential associations with infant sleep consolidation.

While this study was strengthened by the presence of objective measurements, there are several limitations that are important to note and address. The most significant limitation of this study was the small sample size of 13 mother-infant dyads. A larger sample size with more diversity in socioeconomic status would likely provide data that is more representative of the population. With a larger sample size, the possible relationships between household chaos, maternal mental health, and infant sleep consolidation could more confidently be assessed.

A second limitation to this study was the lack of longitudinal data. The high chaos measures were extracted from one day of the participant's collected audio data, and actigraphy

and EMA data was obtained from a range of 1-7 days, depending on wearer compliance and maternal response rates. Because household chaos, maternal mental health, and infant sleep are all complex, dynamic processes, longitudinal data over several weeks or months could provide a better indication of how these variables are interrelated. Additionally, longitudinal data would likely offer a more representative depiction of these factors. For example, it is possible that the audio data selected for a participant was from a day where the family may have had additional people in the household or a busy schedule, which would likely result in a higher number of hours of high chaos. Therefore, a more long-term objective assessment of high household chaos would better illustrate the home environment for each participant.

A third limitation lies in focusing on a single dimension of high household chaos. While audio data provided the advantage of objectively measuring household chaos, this inherently resulted in a larger focus on environmental chaos rather than other components of high household chaos, such as lack of routines, structure, and changing household composition. In the future, audio data collected longitudinally could potentially be used to assess these other characteristics of household chaos to obtain a more holistic assessment of this construct.

Lastly, the sampling algorithm developed by the Daily Activity Lab that was used to find areas of high household chaos within the audio segments to get the automatically-detected high chaos measure is currently in its preliminary stages of development. As such, it may have over- or under-predicted areas of high chaos within the audio files obtained from the LENA sensor. Therefore, is possible there were areas of high household chaos within the audio files that were not present in the automatically-detected high chaos measure and therefore, indirectly affected the human-annotated high chaos measure that is a subset of the automatically-detected high chaos measure. Currently, changes and improvements are being made to the sampling algorithm

to improve the automatically-detected high chaos measure, and future studies that implement the algorithm will benefit from these modifications and obtain a more representative assessment of household chaos.

Future studies should focus on addressing the limitations of the current study. It is possible that the insignificant correlations were due to the small sample size or lack of representative data. Improvements to the study design and methodology could yield more insight into the relationships between household chaos, maternal mental health, and infant sleep consolidation.

Conclusion

Infant sleep consolidation is a highly complex process governed by factors that are equally complex and multifaceted. Qualities of the home environment, such as the amount of household chaos, have shown negative outcomes on infant sleep, along with other areas such as child and adolescent behavior. In this study, household chaos was assessed through audio data, which provided insight into the naturalistic home environment. However, unlike previous studies, this study found that high household chaos was not associated with delays in infant sleep consolidation. While it is possible that high chaos within the home environment may not have as significant of an impact on infant sleep as predicted, further studies with a more robust dataset would elucidate any potential relationships between household chaos and infant sleep consolidation.

Maternal mental health and infant sleep have an intricate relationship. The effects of maternal mental health disorders can be subtle or profound, thereby effecting the interactions a mother has with her infant in a number of ways. While it was predicted that higher symptoms of

maternal mental health disorders would result in delayed infant sleep consolidation, we found that maternal mental health and mood and infant sleep consolidation were not related. It is possible that maternal mental health disorders do not have as profound of an impact on infant sleep consolidation as expected, but further research that accounts for the intricacies and variability of the manifestations of maternal mental health disorders would provide more insight into how it may affect infant sleep consolidation.

Lastly, the absence of significant overlap between the subjective and objective measures of household chaos provide insight into the strengths and weaknesses of both assessments. The human-annotated high chaos measure obtained from audio collected by sensors provides a naturalistic assessment of household chaos, with little room for the involvement of bias. However, the use of this objective measure resulted in a stronger focus on environmental chaos and may have been further restricted by the limitations of the automatically-detected high chaos measure or the lack of long-term data for each participant. However, with the assumption that the auditory assessments of chaos provide a non-biased, objective measure of household chaos, the lack of significant overlap with the self-reported CHAOS measures could suggest that the subjective survey measures contain substantial biases and may not realistically represent the amount of household chaos within a home. As with all surveys and questionnaires, it is important to account for the presence of self-report bias and when possible, use objective measures to supplement the data and obtain a more representative assessment.

The research presented in this thesis primarily served as a pilot study for future research that examines the associations between household chaos, maternal mental health, and infant sleep consolidation. Future studies that examine these factors should encompass a larger sample size that is more representative of the population and aim to integrate data from a longer period

of time. Additionally, adjustments and improvements to the sampling algorithm used to get the automatically-detected high chaos measure (created by the Daily Activity Lab) will be beneficial in more accurately detecting the amount of high chaos present in the audio data obtained from each participant. We hope that the research framework established from this thesis will be used to repeat this study with the above-stated modifications to develop a better understanding of the implications of household chaos and maternal mental health disorders on infant sleep consolidation. Greater insight into these relationships will enable families to implement strategies within the home environment to better facilitate infant sleep consolidation, especially during the first few months of life. Furthermore, a stronger understanding of the potential negative impact of maternal mental health disorders can encourage healthcare providers and mothers to seek treatment and support for mental health disorders.

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Author Biography

Myra was raised in Sugar Land, Texas and attended Stephen F. Austin High School. After high school, she attended The University of Texas at Austin for her undergraduate studies and majored in Neuroscience while completing certificates in Children and Society and Forensic Science. During her time at UT Austin, Myra served as a Peer Academic Coach and Peer Coordinator at Sanger Learning Center where she met and connected with students across all academic backgrounds. She also volunteered at Kindred Hospice where she had the opportunity to spend time with patients in end-of-life care. Myra was involved in the Daily Activity Lab in the Department of Psychology for 2.5 years, where she developed a strong passion for mental health awareness and advocacy.

After completing her bachelor's degree in Neuroscience in May 2021, Myra will begin medical school at McGovern Medical School in Houston, Texas. During her time as a medical student, she hopes to continue advocating for mental health and bringing awareness and healthcare resources to all populations.