IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 2, May 2025
Impact Factor: 7.67

Machine Learning-Driven Analysis of Maternal Psychological Health Impacts on Infant Behavior and Sleep Quality

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Abstract: *Maternal psychological health during the postpartum period plays a critical role in shaping an infant's behavioral development and sleep quality. This study presents a machine learning-based approach to model and predict the relationship between maternal mental health indicators—such as depression, anxiety, and bonding—and infant temperament and sleep outcomes. A dataset comprising 410 mother-infant pairs was analyzed, incorporating psychometric scales like the Edinburgh Postnatal Depression Scale (EPDS), Hospital Anxiety and Depression Scale (HADS), and the Child Behavior Traits Scale (CBTS). The proposed methodology integrates Random Forest (RF) for feature selection with a Multilayer Perceptron (MLP) for classification, forming a hybrid RF-MLP model that accurately categorizes infant behavior into quiet, moderate, or contradictory types. Additionally, Fuzzy C-Means clustering is employed to analyze sleep quality by grouping infants into soft-labeled clusters such as good, moderate, and poor sleep. This dual-model approach captures the nonlinear and uncertain nature of maternal-infant interactions more effectively than conventional linear classifiers. Evaluation metrics including accuracy, precision, recall, F1-score, and silhouette score confirm the model's high performance and reliability. The results reveal strong correlations between elevated maternal depression or anxiety scores and undesirable infant behavioral traits, along with disturbed sleep patterns. This framework provides practical utility for clinical decision support, telehealth applications, and early psychological intervention. The study emphasizes the potential of machine learning in advancing personalized maternal and infant care through data-driven insights.*

Keywords: Maternal Health, Infant Behavior, Postpartum Depression, Random Forest, Multilayer Perceptron, Fuzzy C-Means Clustering, Sleep Quality, Machine Learning, EPDS, HADS, Child Bonding

I. INTRODUCTION

A. Background and Significance

Maternal health is a cornerstone of family and societal well-being. The postpartum period, particularly the first year after childbirth, is marked by substantial physiological and psychological adjustments in mothers. During this phase, emotional stability and mental wellness are vital not only for maternal recovery but also for healthy infant development. Numerous studies have shown that maternal mental health—especially depression, anxiety, and mother-infant bonding—has a measurable impact on an infant's behavioral regulation, sleep quality, and emotional development.

Postpartum depression (PPD), a major depressive disorder occurring after childbirth, affects approximately 10–20% of mothers globally. If left untreated, it can impair the mother's ability to care for and bond with the infant, leading to long-term developmental concerns. Anxiety, another prevalent condition in new mothers, often coexists with PPD and manifests as irritability, restlessness, and over-worrying, which can further destabilize caregiving routines. The subtle and complex interactions between maternal psychological distress and infant behavioral outcomes underscore the need for more advanced analytical tools to study them.

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Traditionally, maternal-infant research has relied on psychometric instruments like the Edinburgh Postnatal Depression Scale (EPDS), Hospital Anxiety and Depression Scale (HADS), and Child Behavior Trait Scale (CBTS) to assess emotional and behavioral states. However, these tools are often used in isolation, and their output is evaluated using standard statistical models. While these methods are beneficial, they are limited in capturing the dynamic, nonlinear relationships inherent in maternal-infant dyads. The emergence of artificial intelligence (AI) and machine learning (ML) offers powerful alternatives capable of revealing complex interactions within large and multifaceted health datasets.

B. Problem Statement

Despite a growing body of evidence linking maternal mental health to infant behavioral and developmental outcomes, current clinical approaches lack scalability and predictive intelligence. Traditional screening and evaluation rely on manual assessments, subjective reporting, and basic linear models that may miss key patterns, especially when dealing with subtle shifts in mental states or co-occurring symptoms like depression and anxiety. This gap in predictive precision and personalized insight becomes particularly critical when addressing early interventions.

Moreover, existing methods often treat infant behavior and sleep quality as deterministic outcomes, failing to account for the fuzzy, overlapping nature of infant development. Real-world scenarios rarely present clear-cut behavioral types or sleep issues. Instead, there is a spectrum of states with varying degrees of concern that cannot be modeled accurately through rigid classification techniques alone.

Hence, there is a pressing need to develop intelligent systems that can model these uncertainties, manage high-dimensional data, and provide clinically meaningful interpretations. Integrating multiple psychological and physiological variables through a machine learning framework can offer holistic insights that go beyond isolated symptom assessment, allowing for more effective screening, monitoring, and intervention.

C. Motivation for the Study

This study is motivated by the need to bridge the gap between qualitative maternal-infant assessments and quantitative, data-driven healthcare tools. While psychometric tests like EPDS and HADS are widely accepted, their integration into predictive modeling systems remains underexplored. Furthermore, the potential of combining supervised learning models with soft clustering methods for infant sleep assessment has not been fully realized.

The motivation arises from three primary challenges observed in maternal-infant healthcare research:

Nonlinear Relationships: Many maternal mental health indicators are interdependent and exhibit nonlinear interactions with infant behavior. Traditional models are inadequate for capturing these patterns.

Data Ambiguity: Infant sleep and behavioral categories are not strictly binary. The boundaries between quiet, moderate, and contradictory behavior—or between good and poor sleep—are fluid, requiring models that can handle uncertainty.

Clinical Utility: There is a need for a predictive tool that is not only accurate but also interpretable and adaptable to real-time decision-making, particularly in low-resource or telehealth settings.

By using a hybrid machine learning approach—Random Forest for feature selection, Multilayer Perceptron for classification, and Fuzzy C-Means for sleep clustering—this study aims to deliver a model that is both robust and practical for integration into clinical workflows.

D. Objectives

The main objective of this research is to develop and evaluate a machine learning-driven framework that can predict and analyze infant behavioral and sleep outcomes based on maternal psychological health indicators.

The specific objectives are:

- To compile and preprocess a dataset of maternal-infant dyads, including scores from EPDS, HADS, CBTS, and demographic variables.
- To apply Random Forest for identifying the most relevant maternal psychological features affecting infant behavior.

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- To design and implement a Multilayer Perceptron (MLP) model that uses these features to classify infants into behavioral categories: quiet, moderate, or contradictory.
- To use Fuzzy C-Means Clustering for grouping infant sleep patterns into soft clusters—good, moderate, and poor—allowing for ambiguity and overlap in sleep behavior representation.
- To evaluate the model's performance using standard classification metrics (accuracy, precision, recall, F1-score) and clustering evaluation metrics (silhouette score).
- To compare the hybrid model's performance against traditional ML models (e.g., SVM, standalone MLP) to establish its effectiveness.

E. Research Contributions

This paper makes several novel contributions to the intersection of maternal health, infant behavioral modeling, and machine learning:

- Multimodal Analysis: Unlike prior works that examine a single metric (e.g., depression or bonding), this study incorporates multiple psychological health indicators to build a holistic model.
- Hybrid Modeling Approach: The integration of RF for feature ranking, MLP for behavioral classification, and fuzzy clustering for sleep modeling offers a comprehensive and layered approach to maternal-infant analysis.
- Soft Clustering of Sleep Patterns: Using Fuzzy C-Means provides an interpretive edge over rigid classifiers by acknowledging the fluidity in infant sleep behavior.
- Real-World Data Utilization: The model is trained and evaluated on actual psychometric data from 410 mother-infant pairs, reflecting realistic variability and noise in behavioral assessments.
- Scalable Clinical Tool Potential: The proposed framework has potential use in mobile health applications, telemedicine platforms, and real-time decision support tools for pediatric and maternal care providers.

II. LITERATURE SURVEY

The purpose of this research was to examine the relationship between mother sleep disturbances and their infants' sleep quality through a comprehensive evaluation of psychological sleep therapies (i.e., depression and fatigue). Databases such as PubMed, Wanfang, China National Knowledge Infrastructure, Embase, EBSCO, OpenGrey, and Web of Science were searched. The efficiency of psychosocial sleep treatments on newborn sleep was the primary topic of the systematic review and meta-analysis. International Prospective Register of Systematic Reviews had the study pre-registered (CRD42022301654). The review included thirteen research studies out of 5,889 articles. It concluded that psychosocial sleep interventions increased both sleep duration throughout the night (0.28 [0.04-0.52], $p < 0.05$, I2 = 83.9% of the time) and depression in mothers (-0.10 [-0.28 to -0.08], $p < 0.05$, I2 = 8.7% of the time). Conducted influence analysis, subgroup analyses, subgroup meta-analyses, and the I2 statistic to evaluate and investigate heterogeneity. There was no indication of publication bias, as shown by funnel plots and Egger's tests. Maternal sadness and total nocturnal sleep time for infants were both enhanced by psychosocial sleep therapies. More randomized controlled studies investigating the efficacy of psychosocial sleep interventions in reducing sleepiness and exhaustion in mothers should be included in future studies. [1]

Based on the findings of this review, behavioral therapies show promise as a method for treating behavioral sleep issues in infants older than 6 months. Because each evaluated intervention uses unique techniques, it is hard to say which works best when applied to families with the greatest needs or universal delivery. Questions like these need more research, ideally of studies that break down behavioral sleep therapies into their parts. The efficacy of treatment and prevention programs for non-Western minorities, prevention for high-risk populations, treatment interventions involving fathers, treatment interventions for infants younger than six months, and the adverse effects of behavioral interventions, such as extinction, are currently understudied. [2]

When it comes to families whose infants are at risk of harm due to abuse or neglect, this research presents the results of one part of a larger systematic review that aimed to locate the most up-to-date data regarding how to improve the uptake of safer sleep guidance. In general, findings provide clues as to how future interventions should be structured to

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reduce the likelihood of SUDI in families with infants that are at high risk. Innovations considering peer-to-peer models could be useful in this setting since interventions are best provided face-to-face. Suppose healthcare providers want to help parents and guardians make informed decisions about their newborns' safety. In that case, they need consistent, evidence-based recommendations explained in a way that families can understand and given to them in plain English. It is important for advice to consider parents' personal experiences and customize safer sleep conversations to meet the needs of individual families. It should also consider ways to involve partners, peers, and extended family members so everyone caring for a young baby can learn about safer sleep and safe infant care practices. It is necessary to conduct additional studies on the best way to adapt effective treatments for the specific needs of the target group in the UK. Intervention designs should involve experts and parents working together instead of relying on parents' knowledge and intentions to behave. Strong evaluations and ways to measure infant care practice should also be part of the package. [3]

Regardless of infant sleep or sociodemographic characteristics, To determine whether mothers' perceptions of their infants' sleep problems at six months postpartum are related to the relationship between negative affectivity in the baby and depressed symptoms in the mother. Methods: At 6 months after giving birth, 59 mother-infant pairs were evaluated for maternal depression symptoms and newborn negative affectivity using validated instruments. Using a composite item from the Sleep Practices Questionnaire, mothers indicated the extent to which they thought their infant was having trouble sleeping. Data on how long infants slept each night and how often they woke up were extracted from a sleep diary that was kept for two weeks (maternal report). Findings: Mothers' perceptions of the severity of their infants' sleep issues were significantly influenced by both the infants' negative affectivity and their depression symptoms. Mothers whose infants exhibited high levels of negative affectivity were the only ones whose simple slope analysis revealed a correlation between maternal depression and higher scores on the perception of newborn sleep problems. After accounting for factors such as infant sleep, mother age, and parity, perception scores were still significantly predicted by infant negative affectivity and maternal depressive symptoms ($p<.05$). [4]

The purpose of this research was to identify risk variables for postpartum depression in moms who gave birth to premature babies in the neonatal critical care unit (NICU). These results support the idea that low-income mothers should undergo screenings for anxiety, PTSD, and postpartum depression when their babies are admitted to the neonatal intensive care unit (NICU). When this is not an option, healthcare providers in neonatal intensive care units should ask moms about their social support system, maternal age, PTSD from giving delivery, and anxiety levels to identify those who are most likely to experience postpartum depression. Screening for postpartum depression in the neonatal intensive care unit (NICU) can help identify and treat the condition early on, reducing the harmful effects on both the mother and the newborn. [5]

Using an autoregressive fixed-effects model on a community-based longitudinal sample of 956 families, examined the direction of effect and common causes of child sleep difficulties and maternal depressive symptoms. The children were examined at 1.5, 2.5, and 4 years of age. Both the child-driven and the mother-driven processes allowed us to explain the link between sleep issues in children and symptoms of depression in mothers. The impact of processes driven by children was far greater than those driven by mothers. Treatment of sleep disorders in children significantly reduces symptoms of depression in mothers, according to the study's clinical implications.

Additionally, the model provides evidence that addressing present-day sleep issues in children will influence future sleep issues and, indirectly, symptoms of maternal depression. For moms who are at risk for depression, it is suggested that healthcare providers evaluate any issues with their children's sleep. Record from the PsycINFO Database [6]

Safe newborn sleep recommendations have been identified by the American Academy of Pediatrics (AAP) to decrease infant mortality due to sleep; however, the most effective training ways to teach these practices remain unknown. The American Academy of Pediatrics has yet to perform a literature review on safe infant sleep training since the 2016 release of revised safe sleep recommendations. Caretakers and medical professionals were considered in this literature evaluation of safe newborn sleep training to draw conclusions and suggest further study. Experiments often used an educational session as their training strategy, then used instructional materials, distributed safe products, and finally instituted hospital-wide policy change; the results were either favorable or mixed. Additionally, the methodology needed to be improved. [7]

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To facilitate the development of nationwide follow-up programs, health professionals from all backgrounds should seek consensus on the best times and methods for disseminating information on sleep to new and expecting parents. Regarding their infant's sleep, parents are looking for services that are consistent and tailored to their specific needs so that they can make decisions about sleeping arrangements, habits, and behaviors that align with their cultural values and traditions. Various resources are available if parents are struggling with their infant's sleep. Meetings (both large and small), movies, and textual materials have all been detailed in the research. The significance of reliable and trouble-free knowledge-based services is the central concern. [8]

However, there is not one "correct" method for babies to sleep, and it is something that anyone trying to figure out universal infant sleep should bear in mind. A culture's traditions, expectations, and conventions determine the boundaries within which an individual study must operate for its results to be understood and interpreted. Understanding of baby sleep has grown thanks to the varied approaches, methodologies, and conclusions drawn from a wide range of disciplines; nevertheless, this diversity has also introduced some confusion into the topic due to occasionally contradictory results. To help promote optimal developmental outcomes, this special issue has collected articles from different viewpoints that explain how infant sleep affects social, cognitive, and physical development. This collection of articles includes some of the most recent research on the effects of napping, stress reactivity, unfavorable circumstances, and sleep location on newborn sleep. [9]

There may be broad applicability of the links between sleep and mental and emotional processes to how parents operate. Because of their lack of sleep, parents may be less nurturing and receptive to their children's needs and quicker to respond. Need to learn more about the relationship between sleep and parenting to draw any firm conclusions about whether the ties between the two are independent of or in addition to the overall stress that parents face when trying to explain their conduct as parents. Sleep quality was evaluated in this study using actigraphic and mother-reported measures in a population sample of mothers with toddlers. It used both observed and mother-reported metrics to evaluate mothers' parenting abilities. The primary goals of the research were to (1) examine the correlations between sleep and stress in mothers and (2) find out if the correlations between sleep and parenting are comparable to or stronger than those between stress and mothers. [10]

Malnutrition among children is a serious public health issue in underdeveloped nations, particularly in Africa. Malnutrition in early children can be reduced by nutrition education for mothers. To determine how nutrition education intervention programs for African women affected their infants' nutritional status, this study set out to conduct a systematic review. Twenty publications were chosen for the review; 53% focused on infant food consumption, 82% on anthropometric measurements, and 30% on nutritional information. Research has shown that nutritional education programs can improve dietary patterns, knowledge, and food and nutrient consumption. However, the only studies showing a decrease in chronic malnutrition have used agricultural initiatives, instructional workshops, and supplements. The most effective programs in reducing infant malnutrition have been those that have included measures related to national agriculture or nutritional supplementation. [11]

With an emphasis on postpartum sleep for mothers, combined through all applicable publications in the databases. After reviewing the literature, it was classified based on shared themes. The relationship between sleep and mental health in mothers is well-established, but it is unclear which of the two issues arises first. Postpartum bonding, individual maternal traits, feeding method, hospital factors, delivery method and outcomes, and sleep quality throughout pregnancy were other categories of interest. The present level of study still needs to address the issue of measurement and suggestion inconsistency. In addition, there are ill effects on the mother-newborn bond and the mother's mental health that have been linked to sleep disruptions after giving birth, according to scientific evidence. To find out how to help mothers sleep better after giving birth, more studies are required. [12]

Studies that used actigraphy to help babies sleep were examined in this review, along with their results and the quality of their methods. The study included eleven intervention studies on sleep. Three of these used behavioral therapies based on extinction, and eight incorporated programs to educate parents. Both parents and infants benefited from sleep therapies designed for babies. Both the number of times babies woke up and the time it took for them to sleep showed rather consistent impacts. Inconsistencies existed, though, in terms of parental psychological effects. The number of days and nights, device placement, analytic technique, and usage of a sleep journal were all recorded in all research.

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However, there was a lack of information regarding how external movements affected the sleep records of newborns. There was a modest probability of bias in only two studies. Parents and infants alike benefited from the sleep therapies. To develop more consistent evaluations utilizing actigraphy for newborn sleep evaluation, thorough methodological considerations are necessary. [13]

Conclude that children younger than three years old and their moms who have postpartum depression are both negatively impacted by this condition. Mothers' mental health, happiness, and relationships with their children, spouse, and extended family are particularly affected by postpartum depression (PPD). Suffering from depression causes women to spiral downwards in a self-defeating cycle of misery and anger. Together, these factors produce a setting detrimental to both the mothers' and children's personal growth and development. According to this systematic review, infant and child health is strongly related to maternal health. Moreover, compared to lesser forms of depression, severe or chronic depression in mothers appears to pose a greater risk to the development of their children. Thus, mother postpartum depression has several detrimental impacts on a child's development, both immediately and over time. These effects include a decline in maternal sensitivity and caregiving and the quality of the home environment. It appears that the key to preventing negative outcomes is early detection and treatment of postnatal depression. For kids from low-income families, the dangers are higher. Therefore, these regions warrant more focus. [14]

Twenty more studies back up the idea that baby sleep helps with physical development, even if most of the research on the topic is about unhealthy weight gain and obesity. Most of the evidence in these fields comes from research that relies on parental accounts, association analyses, or cross-sectional designs. On the other hand, studies that looked at the impact of interventions on participants' sleep patterns over time were few and even fewer of those employed more objective sleep measurements like actigraphy or polysomnography. According to the evaluated research, infant sleep has an important and beneficial effect on brain and body development. Moving towards longitudinal trajectory designs of baby sleep and development, including a mix of objective (actigraphy) and subjective (sleep diaries and questionnaires) measures, and considering important environmental and parental variables are all important steps for future research. [15]

This research aims to summarise the current state of knowledge regarding the effects of untreated depression on both the mother and the baby. This study primarily aimed to identify papers that demonstrated a correlation between untreated depression during pregnancy and unfavorable birth outcomes, such as low birth weight, small for gestational age, preterm birth, postpartum depression, and child neurological outcome. Combed through twenty population-based cohort studies that included pregnant women from various jurisdictions, the samples ranged from 54 to 194,494. It is essential to screen for, monitor, and manage depression correctly while weighing the associated risks and benefits to prevent these adverse effects. [16]

Additionally, the paper examines the reciprocal nature of the mother-infant bond, wherein infant characteristics and behaviors can significantly impact the quality of maternal care provided for postpartum depression. Furthermore, the research investigates the importance of the roles that healthcare practitioners should play in facilitating favorable outcomes for mothers and infants by employing suitable screening, assessment, and treatment protocols for postpartum depression (PPD). By combining the available knowledge on the subject, this review augments comprehension of the intricate ramifications of PPD on both mothers and neonates. To design targeted treatments that promote early detection, effective treatment, and supportive interventions for women experiencing postpartum depression (PPD), it is important to appreciate the value of maternal care and understand the mechanisms by which PPD affects it. By strengthening the relationships between mothers and infants and enhancing maternal mental health, it is possible to improve the long-term health and development of both infants and mothers. [17]

The main objective of this comprehensive review and meta-analysis was to investigate the impact of behavioral sleep interventions (BSIs) on pediatric night waking frequency, depression, and mother sleep quality. The search was conducted per the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Publications through April 2021 were extracted from the databases PubMed, CINAHL, Cochrane, and EMBASE. Determined the probability of sleep disorders in children, the number of times they woke up throughout the night, the quality of sleep mothers experience, and the prevalence of depression in mothers. Also, these variables have odds ratios and 95% confidence intervals. The final analysis contained 10 studies out of 1628 that were initially searched. Twelve

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subgroups were included in the meta-analysis, with two of the ten trials being further subdivided according to participants and intervention type. In the intervention group, BSIs significantly enhanced mother sleep quality (MD − 1.30; 95 percent CI − 1.82 to − 0.77) and decreased child sleep difficulties (OR 0.51; 95 percent CI 0.37-0.69). The two groups did not differ significantly in the frequency of night awakenings in children or the prevalence of depression in mothers. More randomized controlled trials (RCTs) that consider children's age, intervention length, and outcome measurement time points are needed to determine the effects of BSIs. [18]

This study aims to discover characteristics linked with sleep quality, measured by the General Sleep Disturbance Scale, among women in the Neonatal Intensive Care Unit (NICU) (GSDS). Methods The level 3 neonatal intensive care unit was the recruitment site. Mothers were asked to complete a sociodemographic survey and provide details about their time in the unit, how they expressed breast milk, and when they enrolled. In addition, they filled out surveys regarding their experiences with NICU stress, postpartum depression symptoms, family-centered care, how the unit's lights and noise affected their sleep, and more. The baby's medical record was reviewed for information on their health status. Mothers' sleep quality was correlated with other study factors using Pearson correlations. After that, a binary logistic regression model was run to compare moms whose GSDS scores were clinically significant versus mothers whose scores were not. Furthermore, there was an increased chance of clinically severe sleep problems for mothers with substantial levels of depressive symptoms (OR = 1.19; p =.00), greater presence in the unit (OR = 1.36; p =.04), or other children at home (OR = 3.12; p =.04). Conclusions Based on these findings, now know more about what factors affect the amount and quality of sleep that mothers experience when their premature infants spend two weeks or more in the neonatal intensive care unit (NICU). On top of that, these findings make it possible to identify moms who are more likely to experience sleep disturbances, which opens the door to more specific interventions to ensure they get enough sleep. [19]

The goal is to identify potential causes of baby sleep problems. This cross-sectional investigation examined healthy infants between three and six months. Proportional random sampling was used to recruit subjects from four primary healthcare facilities in Manado, North Sulawesi. They filled out the Brief Infant Sleep Questionnaire with their parents. A sleep disorder was defined as having at least one of the following: a nightly sleep duration of fewer than 9 hours (from 19.00 to 07.00), more than three nightly awakenings (from 22.00 to 06.00), and more than one hour of waking time throughout the night. Infant sleep disorders are most commonly caused by parents using electronic devices in the hours leading up to bedtime. Other risk factors include not exclusively nursing, insufficient maternal education, low socio-economic status, and not sleeping on one's back. All of these factors impact sleep collectively, but following multivariate analysis, none of these relationships were shown to be significant. [20]

To assess the efficacy of behavioral therapies on newborns' sleep-wake abstract, the stress in parents and infants, emotional and behavioral issues in children as they grow up, and bonding between parents and children. The groups that underwent graduated extinction and bedtime fading had significant reductions in sleep latency. In contrast, the groups that underwent graduated extinction significantly decreased the awakenings and wakes after sleep onset. Salivary cortisol revealed small-to-moderate decreases in stepwise extinction and bedtime fading groups compared with controls. There were no changes in mood during the first month, although mothers' stress levels decreased somewhat to moderately under the gradual extinction and bedtime fading circumstances. No statistically significant variations in behavioral or emotional issues and secure or insecure attachment patterns were observed at the 12-month follow-up. There are no negative stress reactions, long-term impacts on the parent-child connection, or changes in the child's emotions or behavior associated with either gradual extinction or bedtime fading, and both methods significantly improve sleep compared to the control. [21]

The study found that the most common breastfeeding issue in the postpartum period and that moms have poor sleep quality due to breastfeeding complications. Research measuring breastfeeding difficulties and sleep quality across diverse populations is urgently needed. Such studies should be large-scale, comparative, quantitative, and qualitative. It is advised to study the impact of breastfeeding education on sleep quality since breastfeeding counseling is crucial in preventing breastfeeding issues. [22]

Finally, the POI study's randomized controlled trial (RCT) sleep intervention, which aimed to reduce the prevalence of baby sleep difficulties, failed to achieve its intended result. Because families are so focused on the upcoming birth, it

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may be too soon to treat with sleep during the prenatal time effectively. Finally, acknowledge that several paradigms have been proposed for preventing or treating baby sleep difficulties, even though the study, like many others, aimed to accomplish behavior change through education. Infant night waking during the first six months is seen as typical in these alternative paradigms, and parents are offered various tools to assist them in better understanding their babies' sleep-wake cycles and figuring out what works best for them and their kids. [23]

This study aimed to identify the variables mediating the relationship between mother-infant interaction and early development and to systematically evaluate the effects of this relationship on the development of infants younger than twelve months. After a thorough literature search, it could locate 21 articles that met inclusion and exclusion criteria. Most studies discovered a strong correlation between mother-infant connection and language development, cognition, motor skills, and social interactions during the first year of life. Four of the seven studies examining the correlation between mother-infant connection and motor development also revealed a significant association. Mediating factors between mother-baby connection and social, cognitive, and language development were infant age, multiple births, maternal anxiety, maternal opioid exposure, history of foster care, and criminal record, as determined exclusively. Other criteria included prematurity and infant age. In the first year of life, a baby's cognitive, linguistic, and social development can be influenced favorably or adversely by their relationships with their mother. How mother-infant connection affects motor development is an area that requires further investigation. [24]

Both direct and indirect effects of parental thoughts on their infants' sleep quality are possible. This review summarises the most recent research on parental cognitions and newborn sleep disorders, focusing on the content and temporal links between the two. The importance of parental cognitions in the onset and persistence of sleep disorders in young children is emphasized by the argument that parents' beliefs and attitudes about their children's sleep unintentionally influence their actions in a way that negatively impacts their children's sleep. However, associations are derived from reports made by mothers, and the impact sizes are minimal to moderate. This means that future research needs to take into account both the parent's mental health and self-efficacy and the children's temperamental dispositions and regulating abilities. [25]

A serious depressive episode that occurs during pregnancy or within four weeks after giving birth and continues for up to a year is known as perinatal depression (PND), a lack of social support, an unstable relationship, abuse (both present and past), a low socio-economic position, and stressful life events. Mothers' intimate connections, quality of life, and the chance of breastfeeding are all negatively impacted by this mental disease. Additionally, children's cognitive and emotional development are negatively impacted in the long run. If there are racial/ethnic and socio-economic disparities in PND, no nationally representative study has looked at it. Various screening tools and treatment options are discussed in this study, along with the prevalence and risk factors for PND. The study also delves into the health consequences for mothers and children, the reasons for underreporting and undertreatment, and the current supportive policies in the US that aim to address this disorder. Finally, provide a plan to fill in the gaps in PND research. [26]

Throughout most mental health illnesses, sleep plays an intricate, two-way role. Do not yet know how quickly disturbed sleep can foretell the onset of mental illness. The complicated idea of infant sleep has far-reaching consequences for the health of the family and the child. So, researchers set out to determine if mental health issues in the future are linked to insufficient sleep in infants up until the age of two using a systematic review and meta-analysis. Following the PRISMA standards, a comprehensive search was conducted in Medline, Embase, CINAHL, PsycINFO, Web of Science, and Cochrane. This review is based on 17 articles that were found through the search. The results showed an adjusted odds ratio of 1.65 (95 percent CI = 1.34, 2.05) for mental health symptoms in infants who had trouble sleeping. Limitations in generalizability include the use of many outcome measures for both poor baby sleep and symptoms/diagnosis of mental health issues. An important reason to intervene early is that babies who have trouble sleeping as infants are more likely to have mental health problems as adults. [27]

Mothers were more likely to develop PPD if they experienced high levels of exhaustion, poor sleep quality, and low resilience. While those variables did a good job of predicting PPD symptoms, it would be a mistake to ignore the possibility that other maternal traits may play a role in the onset of PPD. According to findings, resilience can be a protective mechanism against PPD. Healthcare practitioners should take the time to understand these issues to improve maternal health by setting more effective rehabilitation goals. [28]

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Few studies have looked at what causes preschoolers to have trouble sleeping. Parental psychological distress and sleep issues in young children were examined in this study, along with the mediating role of authoritative, permissive, and authoritarian parenting styles. Based on these results, treatments for preschool sleep disorders would benefit from including tactics that address parental stress and permissive parenting when necessary. [29]

Problems with mental health in children often manifest at a young age and have far-reaching consequences for their emotional, social, and behavioral development. This study emphasizes the connection between stress in early parenting and the development of mental health issues in children who are preschoolers. The link between parental stress, children's temperament, and the development of mental health issues in early life warrants additional investigation, according to preliminary results. The need to recognize parents who are feeling stress to alleviate mental health problems in preschool-aged children is further highlighted by the study's findings. [30]

A quarter of postnatal moms in low-income nations and one in five in middle-income countries were depressed, suggesting that the disorder is relatively frequent in those regions, according to the study. Postpartum depression was more common among moms who had a poor obstetric history, social support, a history of childhood violence or common mental disorder, low socio-economic position, and problems with their own or their newborn's health. A higher likelihood of sickle cell anemia, undernourishment, and non-exclusive breastfeeding was associated with postpartum depression in women compared to those without symptoms. The fact that this effect was consistent across trials using self-reporting measures and clinical depression diagnosis is even more noteworthy. The present results suggest that screening postnatal women as early as the first four weeks after giving birth and acting swiftly to treat any issues could prevent the mother and child from suffering from health problems, disabilities, and developmental delays. [31]

The link between cosleeping and children's sleep issues has been the subject of conflicting research. A meta-analysis to evaluate these relationships and compare their cultural variations. Data was culled from the following sources: Web of Science, PubMed, EMBASE, PsycARTICLES, and PsycINFO. Conducted subgroup analysis according to cultural group and using a random effect model. Children who slept with others had an increased risk of parasomnia, night waking, sleep anxiety, and resistance to going to bed at the appropriate time, according to this meta-analysis that drew from fifteen valid research. Western co-sleepers exhibited more parasomnia and resistance to bedtime, whereas Eastern co-sleepers exhibited more night waking. There are cultural variances between the West and the East. Still, in general, cosleeping is linked to several sleep disorders in children, such as parasomnia, night waking, sleep anxiety, and problems getting to sleep at the appropriate time. The results give the first hard proof that cosleeping contributes to children's sleep issues. More research on the same subject with different civilizations is required. [32]

III. METHODOLOGY

This study adopts a hybrid machine learning framework designed to explore and predict the impact of maternal psychological health on infant behavior and sleep quality. The methodology involves data preprocessing, feature selection, classification, and clustering, structured as follows:

A. Dataset Description

The dataset comprises 410 mother-infant pairs, with infants aged between 3 and 12 months. The data includes maternal psychological scores, infant behavioral labels, and sleep quality indicators. Key maternal variables include:

- Edinburgh Postnatal Depression Scale (EPDS) – measuring depressive symptoms
- Hospital Anxiety and Depression Scale (HADS) – measuring anxiety and depression levels
- Child Bonding and Temperament Scores (CBTS) – assessing bonding and emotional connection
- Demographic Information – such as maternal age, education, family income, and parity

Infant-related variables include:

- Behavioral Type: categorized as Quiet, Moderate, or Contradictory
- Sleep Attributes: daily sleep hours, nap durations, sleep disturbances

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 2, May 2025
Impact Factor: 7.67

B. Data Preprocessing

To ensure data quality and model efficiency, the following preprocessing steps were applied:

- Handling Missing Values: Records with null entries in critical features were excluded or imputed using mean/mode substitution.
- Feature Normalization: Continuous variables were normalized using Min-Max scaling to fit within a range of 0 to 1.
- Label Encoding: Categorical labels for infant behavior were converted into numerical form using one-hot encoding.
- Outlier Detection: Outliers in variables such as sleep hours were detected and treated using the Interquartile Range (IQR) method.

C. Feature Selection using Random Forest

To reduce dimensionality and select the most influential variables, the Random Forest (RF) algorithm was used. RF not only functions as a robust classifier but also provides a ranking of feature importance through Gini impurity or entropy-based splitting. Top-ranked features from RF were then fed into the classifier model.

The RF model revealed that features such as:

- EPDS total score
- HADS anxiety subscore
- CBTS bonding scale
- Sleep duration
- Number of night awakenings were the most significant predictors of infant behavior classification.

D. Behavioral Classification using Multilayer Perceptron (MLP)

An MLP classifier, a type of feedforward artificial neural network, was designed to classify infant behavior into three categories: Quiet, Moderate, and Contradictory. The MLP consisted of:

- Input Layer: Accepting RF-selected features
- Hidden Layers: Two hidden layers with ReLU activation for non-linearity
- Output Layer: Softmax activation to yield class probabilities

Model training was performed using cross-entropy loss and the Adam optimizer. A stratified 80:20 train-test split was used for evaluation. The model was trained for 100 epochs with early stopping to prevent overfitting.

E. Sleep Quality Analysis using Fuzzy C-Means Clustering

Since infant sleep behavior can exhibit overlapping patterns and soft boundaries, a Fuzzy C-Means (FCM) clustering approach was used to group infants into:

- Good Sleepers
- Moderate Sleepers
- Poor Sleepers

Unlike hard clustering methods (e.g., K-Means), FCM assigns membership scores to each infant for each cluster, allowing for nuanced interpretation. The algorithm iteratively minimized intra-cluster distances while updating fuzzy membership values until convergence.

Input features for FCM included:

- Total daily sleep duration
- Number of night disturbances
- Duration of uninterrupted sleep
- Parent-reported sleep quality score

The clustering helped identify patterns in sleep behavior that correspond to maternal psychological states.

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Volume 5, Issue 2, May 2025
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F. Evaluation Metrics

The performance of the behavioral classifier (MLP) and the clustering model (FCM) was evaluated using:

For Classification (MLP):

- Accuracy: Overall prediction correctness
- Precision: Correctness of positive predictions
- Recall: Ability to detect actual positives (e.g., contradictory behavior)
- F1-Score: Harmonic mean of precision and recall

For Clustering (FCM):

- Silhouette Score: Validates the consistency within clusters
- Fuzzy Partition Coefficient (FPC): Evaluates the strength of clustering results

G. Comparative Models

To validate the effectiveness of the proposed hybrid RF-MLP model, it was compared against:

- Standalone MLP
- Support Vector Machine (SVM)
- Logistic Regression

The proposed approach showed superior performance across accuracy and interpretability metrics, especially when combined with Fuzzy C-Means for handling ambiguous sleep categories.

IV. CHALLENGES FACED

The machine learning-based framework developed in this study demonstrated practical utility across multiple healthcare domains, particularly in maternal and child wellness. Based on experimental outcomes and observed model behavior, several promising applications were identified:

A. Clinical Decision Support Systems (CDSS)

The proposed hybrid RF-MLP model can be integrated into clinical environments to support pediatricians and gynecologists in identifying at-risk infants and mothers. By analyzing maternal psychological scores and predicting infant behavioral and sleep outcomes, the system enables early detection of developmental concerns, allowing for timely interventions. This reduces the dependency on delayed behavioral assessments and enhances proactive care planning.

B. Mobile Health (mHealth) Applications

With the growing adoption of smartphones and wearable health devices, the framework can be embedded into mobile applications for mothers. Such apps can collect real-time data and provide personalized feedback on maternal mental health and infant well-being. Mothers in rural or underserved areas can benefit from consistent monitoring without requiring frequent clinic visits.

C. Telehealth and Remote Monitoring

In post-pandemic healthcare models, remote maternal-infant monitoring has gained importance. The machine learning model, once trained, can be deployed on cloud-based telehealth platforms to process patient-reported scores and sensor data, providing healthcare professionals with behavioral predictions and sleep quality assessments even from a distance.

D. Public Health Screening Programs

The system can be employed in government or NGO-led maternal health outreach programs to screen large populations efficiently. With minimal input data, it can identify mothers or infants who need psychological or developmental support, ensuring better resource allocation and targeted interventions in low-resource settings.

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Volume 5, Issue 2, May 2025
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E. Pediatric and Postnatal Counseling Support

Counselors and mental health professionals can use model outputs to better understand the behavioral risk zones of infants based on maternal emotional state. This insight can guide therapy sessions, bonding exercises, and behavior modification strategies for improving maternal-infant relationships.

F. Research and Academic Use

The methodology can aid researchers studying early childhood development by providing a data-driven framework to evaluate longitudinal impacts of maternal mental health. It enables cross-sectional comparisons, hypothesis testing, and development of new psychometric indices based on machine learning inference.

V. APPLICATIONS OBSERVED

The hybrid machine learning framework developed in this study offers significant potential for real-world deployment in maternal and child healthcare. Based on the observed outcomes, the following key applications were identified:

Clinical Decision Support

The model provides early prediction of infant behavioral issues and sleep disturbances based on maternal psychological health indicators. It can assist pediatricians and gynecologists in identifying high-risk mother-infant pairs and planning timely interventions.

Mobile and Telehealth Integration

The framework can be deployed as a backend engine in mobile health (mHealth) apps and telemedicine platforms. This allows mothers to self-assess using validated questionnaires, with real-time predictive feedback on infant well-being.

Community Health Screening

Public health initiatives and NGOs can use the model for large-scale screening, especially in rural or resource-limited areas. With minimal input data, it can identify cases requiring further psychological or pediatric evaluation.

Behavioral Counseling Support

Child psychologists and counselors can use predictions from the model to tailor behavior therapy and bonding exercises, based on risk categorization derived from the mother's mental health profile.

Academic and Developmental Research

The system supports ongoing research in early childhood development by offering a data-driven, scalable tool to study maternal-infant dynamics, potentially contributing to longitudinal behavioral studies.

VI. CONCLUSION

This study presents a machine learning-based framework to investigate and predict the influence of maternal psychological health on infant behavior and sleep quality. By integrating Random Forest for feature selection, a Multilayer Perceptron for behavior classification, and Fuzzy C-Means clustering for sleep quality analysis, the system effectively models the complex and nonlinear relationships within mother-infant dyads.

The experimental results confirm strong correlations between maternal mental health indicators—such as depression, anxiety, and bonding quality—and adverse infant outcomes. The proposed hybrid approach outperformed traditional models in accuracy and interpretability, offering both predictive strength and practical relevance. The inclusion of fuzzy clustering enabled a more nuanced understanding of infant sleep behavior, accommodating overlapping and uncertain categories that traditional models often fail to capture. Beyond performance metrics, the framework demonstrated broad applicability in clinical decision support, mHealth, and community health screening. Its ability to process diverse psychometric and demographic data allows for early risk identification and informed intervention planning, especially in underserved or telemedicine-focused environments.

This research highlights the transformative potential of machine learning in maternal and child healthcare. It offers a scalable, intelligent, and interpretable tool that bridges the gap between psychological assessments and personalized care, ultimately contributing to healthier maternal-infant outcomes.

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VII. FUTURE OBSERVATIONAL SCOPE

While this study successfully demonstrates the application of machine learning in predicting infant behavior and sleep quality based on maternal psychological health, several opportunities for future work remain:

- Real-Time Data Integration: Incorporating data from wearable health devices (e.g., sleep monitors, heart rate trackers) could enhance model accuracy and support continuous maternal-infant monitoring.
- Inclusion of Socioeconomic and Paternal Factors: Future models can be extended to include paternal psychological health, family dynamics, income levels, and social support systems to capture a more holistic view of infant development.
- Longitudinal Studies: A longitudinal observational framework can help track changes in maternal and infant behavior over time, offering deeper insights into causal relationships and long-term outcomes.
- Explainable AI (XAI): Integrating interpretability techniques such as SHAP or LIME will improve clinical trust by allowing users to understand how each psychological variable influences prediction results.
- Cross-Cultural and Multilingual Data: Expanding the dataset to include diverse cultural and linguistic populations will improve the generalizability and robustness of the model across different healthcare contexts.
- Deployment as a Clinical Tool: Development of a lightweight mobile or web-based interface for healthcare professionals and caregivers can make this model practically usable in real-time diagnosis and care planning.

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