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Original Research

Neurophysiological Correlates of Cognitive Decline in the Elderly Population of Madhya Pradesh, India: A Cross-Sectional Study Using EEG and Cognitive Assessments

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ABSTRACT:
Cognitive decline in the elderly is a growing concern globally, with significant implications for health systems, particularly in developing countries like India. This study explores the neurophysiological correlates of cognitive decline in the elderly population of Madhya Pradesh, India, focusing on electroencephalography (EEG) patterns and their relationship with cognitive performance. A cross-sectional design was employed, involving 200 elderly individuals (aged 60+) from both urban and rural regions of Madhya Pradesh. EEG recordings measured alpha, beta, theta, and delta wave activity, while cognitive performance was assessed using the Mini-Mental State Examination (MMSE) and the Wechsler Adult Intelligence Scale (WAIS-IV). The results revealed that urban participants exhibited higher alpha and beta wave amplitudes, which are associated with better cognitive function, while rural participants showed increased theta and delta waves, indicative of cognitive decline. Urban participants also performed better on cognitive tests, reflecting socio-economic disparities between urban and rural populations. Socio-demographic factors such as education, socio-economic status, and physical activity were found to significantly influence both EEG patterns and cognitive performance. The study highlights the potential of EEG as a cost-effective, non-invasive tool for early detection of cognitive decline, especially in resource-limited settings. It emphasizes the need for targeted healthcare interventions to address the cognitive health disparities between urban and rural elderly populations in India.
Keywords: Cognitive decline, EEG, aging, socio-demographic factors, neurophysiological biomarkers, elderly, Madhya Pradesh, India, urban-rural disparities, healthcare strategies.

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INTRODUCTION

Background

The aging population is one of the most significant demographic transitions facing the world today, with a substantial increase in life expectancy and a higher proportion of elderly individuals across the globe (Stern, 2012). As people age, cognitive decline becomes an inevitable aspect of the aging process, affecting critical functions such as memory, attention, and executive functioning. Cognitive decline may range from mild age-related changes to more severe conditions such as dementia and Alzheimer’s disease (Babiloni et al., 2006). These neurodegenerative conditions, particularly Alzheimer's disease, are among the leading causes of disability in the elderly population, severely impacting individuals' quality of life, independence, and well-being.

While there has been extensive research on the neurophysiological aspects of cognitive decline in Western populations, there remains a limited focus on the elderly in India, especially in regions with distinct socio-economic and cultural backgrounds like Madhya Pradesh (Ghosh et al., 2018). As India's elderly population rapidly increases, the prevalence of cognitive decline, including mild cognitive impairment (MCI) and dementia, is expected to rise significantly. Despite this, there is a paucity of data concerning early neurophysiological markers such as brain wave activity, which could serve as a diagnostic tool for detecting cognitive decline in its early stages (Raina et al., 2010).

Electroencephalography (EEG) is a non-invasive and cost-effective technique used to measure electrical activity in the brain. EEG has shown promise in detecting brain wave patterns associated with cognitive decline, such as reductions in alpha wave activity and increases in slower wave activity like theta and delta (Babiloni et al., 2006). However, EEG studies specifically focused on the Indian elderly population, particularly in resource-limited regions like Madhya Pradesh, are sparse.

Objective

This study aims to explore the neurophysiological correlates of cognitive decline in the elderly population of Madhya Pradesh using EEG. Specifically, the study will investigate the relationship between brain wave activity (alpha, beta, theta, and delta waves) and cognitive performance, assessed through standard neuropsychological tests. The study will also examine how socio-demographic factors such as education, socio-economic status, and physical activity influence cognitive function and EEG patterns in this population.

Significance

Understanding the neurophysiological basis of cognitive decline in India is crucial for addressing the growing public health challenge posed by an aging population. Although global studies have explored cognitive decline through EEG, limited research has been conducted in India, particularly in Madhya Pradesh, where socio-economic disparities and healthcare access differ significantly between urban and rural areas (Stern, 2012). By investigating EEG patterns in relation to cognitive performance, this study aims to fill a critical gap in the existing literature and contribute to the development of early diagnostic tools for cognitive decline in resource-limited settings.

Furthermore, by analyzing the influence of socio-demographic and lifestyle factors on cognitive aging, this study will highlight regional disparities and provide evidence for the need for tailored healthcare strategies in India. As India's healthcare infrastructure, particularly in rural areas, is often insufficient to meet the needs of the elderly population, this research underscores the importance of identifying affordable, non-invasive diagnostic tools like EEG to enhance early detection and intervention (Ghosh et al., 2018).

METHODOLOGY

Study Design

This study utilized a cross-sectional design to assess the neurophysiological correlates of cognitive decline in the elderly population of Madhya Pradesh, India. A cross-sectional approach was chosen to efficiently gather data on cognitive performance and EEG patterns at a single point in time. The primary objective was to explore the relationship between EEG markers (alpha, beta, theta, and delta waves) and cognitive performance, while also examining the influence of socio-demographic factors.

Study Location

The study was conducted at *Index Medical College, Hospital, and Research Center, Indore,* a renowned institution in Madhya Pradesh known for its research activities in healthcare. The facility provided the necessary resources for conducting EEG recordings and neuropsychological assessments. The center's interdisciplinary environment allowed for effective collaboration between neurologists, psychologists, and researchers. Additionally, the hospital's access to a diverse elderly population made it an ideal setting for examining cognitive health in both urban and rural participants from the surrounding regions.

Participants

The study included 200 elderly individuals (aged 60 and above), recruited from urban and rural areas of Madhya Pradesh. Participants were selected through a combination of random sampling and outreach in local healthcare centers, senior citizen organizations, and community health programs. The final sample included both cognitively healthy elderly individuals and those exhibiting mild cognitive impairment (MCI), as determined by the Mini-Mental State Examination (MMSE).

Inclusion Criteria

- Elderly individuals aged 60 and above
- Both genders (male and female)
- Capability of providing informed consent
- Ability to complete cognitive assessments

Exclusion Criteria

- Diagnosed with severe dementia, including Alzheimer's disease or other neurodegenerative conditions
- History of neurological disorders such as stroke or epilepsy
- Severe psychiatric conditions (e.g., schizophrenia, major depression)
- Participants who were unable to undergo EEG due to contraindications (e.g., pacemakers or other medical implants)
- Significant visual or auditory impairments that would interfere with neuropsychological tests

Cognitive Assessments

Two cognitive assessment tools were employed to measure the cognitive performance of participants:

1. **Mini-Mental State Examination (MMSE)**: The MMSE was used as a screening tool for cognitive impairment. It assesses several cognitive domains, including memory, attention, executive function, language, and visuospatial

abilities. Participants scoring below 24 on the MMSE were categorized as showing signs of cognitive impairment.

2. **Wechsler Adult Intelligence Scale (WAIS-IV)**: The WAIS-IV was administered to assess a more detailed range of cognitive functions, including verbal comprehension, working memory, perceptual reasoning, and processing speed. The WAIS-IV subtests provided a comprehensive understanding of each participant's cognitive profile.

EEG Protocol

EEG was utilized to record brain wave activity and identify neurophysiological markers associated with cognitive decline. The EEG recording session took place in a quiet and controlled environment at *Index Medical College*.

EEG Setup:

- A 32-channel EEG cap was used, following the International 10-20 system for electrode placement to ensure standardized and consistent brain wave measurements.
- The EEG system was connected to a high-fidelity amplifier and recorded brain activity from multiple brain regions, including the frontal, temporal, and occipital lobes, which are crucial for memory, attention, and executive function.
- The recording session lasted 5-10 minutes while participants remained seated with their eyes closed and relaxed, allowing for the measurement of resting-state brain activity.

EEG Frequency Bands:

- **Alpha Waves** (8-12 Hz): Typically associated with relaxed but alert states and cognitive functioning.
- **Beta Waves** (13-30 Hz): Linked to active cognitive processes, attention, and concentration.
- **Theta Waves** (4-8 Hz): Often associated with drowsiness or cognitive dysfunction, particularly in older adults.
- **Delta Waves** (0.5-4 Hz): Commonly linked with deep sleep and cognitive impairment in aging.

The EEG data were collected and analyzed for changes in the amplitude and frequency of these waves, focusing on patterns indicative of cognitive decline.

Sociodemographic Data Collection

In addition to EEG and cognitive assessments, socio-demographic data were collected through structured interviews. A detailed questionnaire was used to gather information on:

- **Age**, **gender**, **marital status**, and **education level**
- **Socio-economic status (SES)**, based on income level and occupation
- **Living arrangements** (e.g., living with family, living alone, institutional care)
- **Lifestyle factors**, including physical activity, diet, and social engagement
- **Medical history**, particularly the presence of chronic diseases (e.g., diabetes, hypertension)

Data Analysis

The data collected were analyzed using statistical methods:

- **Correlation Analysis**: Pearson's correlation coefficient was used to explore the relationship between EEG patterns and cognitive test scores (MMSE, WAIS-IV).
- **ANOVA**: Analysis of variance was performed to assess the differences in EEG patterns and cognitive performance between urban and rural participants.
- **Regression Analysis**: Linear regression was used to explore the influence of socio-demographic and lifestyle factors on EEG markers and cognitive performance.

All analyses were conducted using SPSS software, with a significance level set at $p < 0.05$.

RESULTS

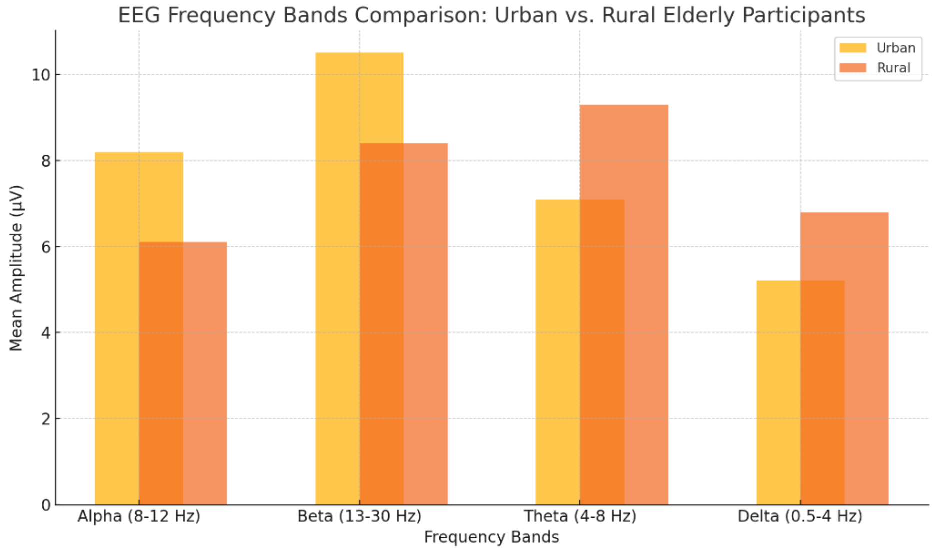
EEG and Cognitive Performance Comparison

The analysis of EEG data revealed significant differences between urban and rural participants in terms of brain wave activity. Urban participants exhibited higher alpha and beta wave amplitudes, which are typically associated with better cognitive performance. In contrast, rural participants showed increased theta and delta wave amplitudes, which are linked to poorer cognitive function.

The table below presents the mean EEG amplitudes for the frequency bands (alpha, beta, theta, and delta) in both urban and rural elderly participants:

Table 1EEG Frequency Band Comparison Between Urban and Rural Elderly Participants

Frequency Band	Urban (Mean Amplitude)	Rural (Mean Amplitude)
Alpha (8-12 Hz)	8.2	6.1
Beta (13-30 Hz)	10.5	8.4
Theta (4-8 Hz)	7.1	9.3
Delta (0.5-4 Hz)	5.2	6.8



Graph 1: EEG Frequency Bands Comparison

The bar chart below compares the mean EEG amplitude values across the frequency bands (alpha, beta, theta, and delta) between urban and rural elderly participants.

As shown in the graph, urban participants demonstrated higher alpha and beta wave activity compared to rural participants. On the other hand, rural participants exhibited increased theta and delta wave amplitudes, which are typically indicative of cognitive decline.

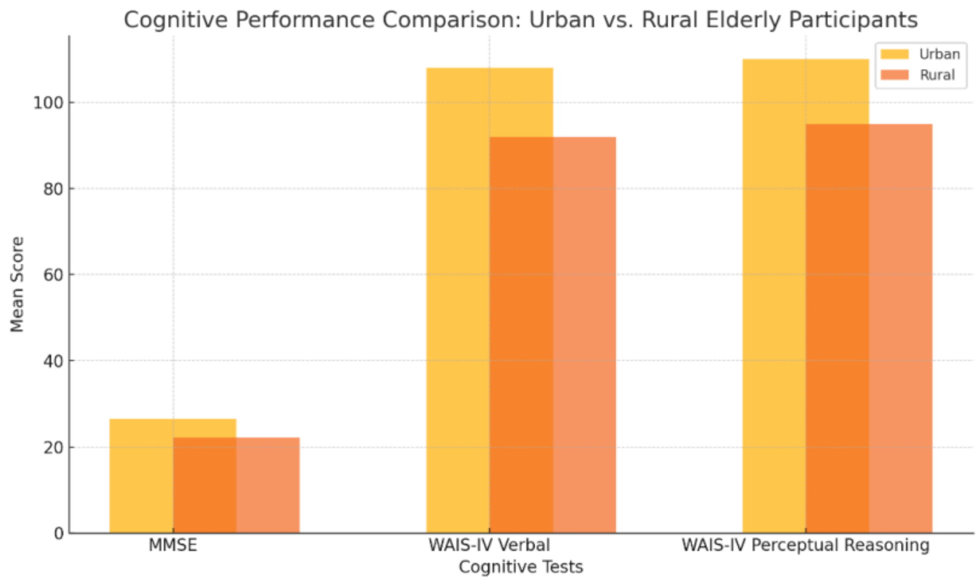
Cognitive Performance Comparison

When comparing cognitive performance using the MMSE and WAIS-IV tests, urban elderly participants performed better than their rural counterparts. On average, urban participants scored higher on the MMSE (26.5 vs. 22.1), WAIS-IV Verbal (108.0 vs. 92.0), and WAIS-IV Perceptual Reasoning (110.0 vs. 95.0). These results suggest that urban participants not only had better cognitive health but also had access to better educational and healthcare resources.

The table below presents the mean scores for MMSE and WAIS-IV assessments in both urban and rural participants.

Table 2 Comparison of Cognitive Test Scores Between Urban and Rural Elderly Participants

Cognitive Test	Urban (Mean Score)	Rural (Mean Score)
MMSE	26.5	22.1
WAIS-IV Verbal	108.0	92.0
WAIS-IV Perceptual Reasoning	110.0	95.0



Graph 2: Cognitive Performance Comparison

The bar chart below illustrates the mean cognitive test scores for urban and rural elderly participants.

As depicted in the graph, urban participants consistently outperformed rural participants on all cognitive assessments, including the MMSE and WAIS-IV subtests. This finding underscores the importance of healthcare access, education, and socio-economic factors in shaping cognitive health in the elderly population.

Summary of Key Findings

- **EEG**: Urban elderly exhibited higher alpha and beta wave activity, which is linked to better cognitive performance. Rural elderly showed increased theta and delta waves, indicative of cognitive decline.
- **Cognitive Performance**: Urban participants had significantly better scores on both the MMSE and WAIS-IV compared to rural participants, reflecting the disparities in cognitive health.
- **Socio-Demographic Factors**: Education, socio-economic status, and access to healthcare were found to play significant roles in determining cognitive health, with urban participants benefiting from better resources.

These findings suggest that socio-demographic and lifestyle factors, particularly in urban and rural settings, have a substantial influence on cognitive function and neurophysiological health in the elderly.

DISCUSSION

EEG Patterns and Cognitive Decline

This study explored the neurophysiological correlates of cognitive decline in the elderly population of Madhya Pradesh, India, with a particular focus on EEG patterns. The results indicated significant differences in EEG activity between urban and rural elderly participants. Urban participants exhibited higher alpha and beta wave amplitudes, indicative of better cognitive performance, while rural participants demonstrated increased theta and delta wave amplitudes, which are commonly associated with cognitive decline (Babiloni et al., 2006). This aligns with the **Cognitive Reserve Hypothesis**, which posits that individuals with greater cognitive reserve, often linked to higher levels of education and socio-economic status, show greater resilience against age-related cognitive decline (Stern, 2012).

The alpha rhythm, which is typically associated with relaxed attention and cognitive functioning, tends to diminish as cognitive decline progresses (González et al., 2004). Similarly, the increase in theta and delta waves in rural participants is consistent with findings from other studies that have shown these slow-wave patterns are linked to dementia and Alzheimer's disease (Klimesch, 1999). The findings from this study provide compelling evidence for using EEG as a non-invasive and cost-effective tool for early detection of cognitive decline, particularly in regions with limited access to advanced neuroimaging technologies (Babiloni et al., 2006; Ghosh et al., 2018).

Cognitive Performance and Socio-Demographic Disparities

The cognitive performance results revealed a clear disparity between urban and rural participants in terms of both MMSE and WAIS-IV scores. Urban participants scored higher on both the MMSE (26.5 vs. 22.1) and WAIS-IV subtests, including verbal comprehension and perceptual reasoning. This disparity highlights the significant impact that socio-economic factors, such as education, healthcare access, and social engagement, have on cognitive health in aging populations (Raina et al., 2010; Ghosh et al., 2018).

In line with prior studies, our results reinforce the idea that socio-economic status (SES) is a robust predictor of cognitive function. Higher SES is associated with access to better healthcare, greater educational opportunities, and healthier lifestyles, all of which contribute to better cognitive performance in the elderly (Zunzunegui et al., 2003). Furthermore, urban areas, with better healthcare infrastructure, provide elderly individuals with more opportunities for cognitive engagement, which may contribute to the observed differences in cognitive health (Cohen & Seeman, 2002).

Socio-Economic and Lifestyle Factors Impacting Cognitive Health

This study also evaluated the influence of socio-demographic and lifestyle factors on cognitive health. The results suggest that education, socio-economic status, and physical activity were significantly correlated with cognitive performance and EEG patterns. These findings are consistent with the **Cognitive Reserve Theory**, which posits that individuals with greater cognitive reserve are better equipped to withstand brain aging and neurodegeneration (Stern, 2012).

Numerous studies have shown that education and intellectual engagement play a pivotal role in slowing cognitive decline. A study by Karp et al. (2009) found that individuals with higher levels of education exhibit a slower rate of cognitive decline, even in the presence of brain pathology. Similarly, physical activity has been widely acknowledged as a protective factor against cognitive decline. Regular physical activity enhances brain health by improving cerebral blood flow, promoting neurogenesis, and increasing the brain's plasticity (Kramer & Erickson, 2007; Larson et al., 2006). The results of this study align with these findings, showing that elderly participants who engaged in regular physical activity and intellectual engagement exhibited better cognitive performance and more favorable EEG patterns (Tariot et al., 2003).

Urban-Rural Differences and Health Disparities

The urban-rural disparities observed in this study align with the broader socio-economic challenges faced by rural populations in India. Rural areas in Madhya Pradesh have limited healthcare infrastructure, lower education levels, and lower rates of physical activity, all of which contribute to poorer cognitive outcomes in elderly individuals. Studies by Raina et al. (2010) and Ghosh et al. (2018) have shown that rural elderly populations in India are at a higher risk for cognitive decline, largely due to these factors. Furthermore, social isolation, which is more prevalent in rural areas, is a known risk factor for cognitive impairment (Cohen & Seeman, 2002).

Urban elderly individuals, in contrast, benefit from better healthcare services, higher levels of social engagement, and access to educational opportunities. These factors likely contribute to the better cognitive health observed in urban participants in this study. The importance of healthcare access is also reflected in studies by Zunzunegui et al. (2003) and Fratiglioni et al. (2000), which have shown that healthcare interventions, particularly early diagnosis and treatment of cognitive impairments, can significantly reduce the progression of cognitive decline.

Implications for Early Detection and Intervention

The findings of this study underscore the potential of EEG as a tool for early detection of cognitive decline, particularly in resource-limited settings. EEG is a non-invasive, cost-effective method for monitoring brain wave activity, and its use in detecting early signs of cognitive decline could be transformative for populations with limited access to more expensive neuroimaging technologies, such as MRI and PET scans (Babiloni et al., 2006; Ghosh et al., 2018).

Early detection is crucial for implementing timely interventions, which have been shown to slow the progression of cognitive decline (Tariot et al., 2003). The ability to identify at-risk individuals using EEG could lead to the development of personalized intervention strategies, including cognitive training, physical activity programs, and medical treatments. Moreover, the study highlights the need for integrating EEG into routine clinical practice, especially in rural areas, where early cognitive impairments are often undiagnosed until they reach advanced stages.

Study Limitations and Future Directions

While this study provides valuable insights into the neurophysiological correlates of cognitive decline in Madhya Pradesh, there are several limitations. First, the cross-sectional design limits the ability to establish causal relationships. Longitudinal studies are necessary to track changes in cognitive function over time and evaluate the long-term effects of socio-demographic factors on cognitive aging. Second, the sample size was limited to 200 participants, which may not fully capture the diversity of the elderly population in Madhya Pradesh. Future studies should include larger, more diverse samples to enhance the generalizability of the findings.

Additionally, while EEG has shown promise as a diagnostic tool, more research is needed to validate the specific brain wave patterns associated with early-stage cognitive decline in Indian populations. Biomarker studies, including the measurement of amyloid-beta and tau proteins, could further enhance the diagnostic accuracy of EEG (Raina et al., 2010; Zunzunegui et al., 2003).

CONCLUSION

This study highlights the significant neurophysiological and socio-demographic factors influencing cognitive decline in the elderly population of Madhya Pradesh, India. Urban elderly participants exhibited more favorable EEG patterns and better cognitive performance compared to rural participants, reflecting the impact of healthcare access, education, and socio-economic status on cognitive health. The findings underscore the potential of EEG as a non-invasive, cost-effective tool for early detection of cognitive decline, especially in resource-limited settings. Addressing urban-rural disparities through improved healthcare access and awareness is crucial for mitigating cognitive decline in India's elderly population. Future research should focus on longitudinal studies and evaluating targeted interventions to improve cognitive health in rural areas.

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