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THE ROLE OF REM SLEEP IN CONSOLIDATING EXECUTIVE FUNCTION: A PREFRONTAL CORTEX PERSPECTIVE

Original Research

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Acknowledgement: The authors gratefully acknowledge the participants for their valuable time and contribution to this study.

Conflict of Interest: None

Grant Support & Financial Support: None

ABSTRACT

Background: Rapid Eye Movement (REM) sleep plays a critical role in the consolidation of higher-order cognitive functions, particularly those governed by the prefrontal cortex (PFC), such as working memory, inhibitory control, and cognitive flexibility. Given the increasing evidence linking sleep quality with executive performance, this study investigates how REM sleep influences these essential functions and how sleep disruption may lead to cognitive and emotional impairments.

Objective: To examine the relationship between REM sleep quality and executive functions—including working memory, inhibitory control, and cognitive flexibility—and to evaluate how sleep disruptions affect these cognitive domains.

Methods: A cross-sectional observational study was conducted between July and September 2024, involving 145 Pakistani adults aged 18 to 70 years. Participants were recruited using convenience sampling. The Pittsburgh Sleep Quality Index (PSQI) was utilized to assess overall and REM-related sleep quality, while executive functioning was measured using the Frontal Assessment Battery (FAB). Stress levels and cognitive failures were also evaluated. Pearson and Spearman correlation analyses were performed based on normality distribution ($p < 0.05$).

Results: A significant positive correlation was found between REM sleep quality and executive function performance ($r = 0.452$, $p < 0.01$). Participants sleeping 7–8 hours reported the highest FAB scores (mean = 11.03 ± 1.98), while those sleeping less than 5 hours had the lowest (mean = 9.18 ± 3.46). Cognitive failure was most prevalent among individuals with <5 hours of sleep (mean = 57.00 ± 23.59), who also reported elevated stress levels (mean = 7.18 ± 3.19). Females exhibited higher cognitive failures (mean = 33.12 ± 19.21) and stress (mean = 5.70 ± 2.55) compared to males. Older adults showed slightly lower frontal lobe functioning compared to younger participants.

Conclusion: REM sleep strongly contributes to the consolidation of executive functions by enhancing PFC-related synaptic plasticity. Disrupted REM sleep is linked to impaired cognitive flexibility, working memory, and emotional regulation, suggesting that improving sleep quality may serve as a vital strategy for cognitive enhancement.

Keywords: Cognitive Flexibility, Emotional Regulation, Executive Function, Prefrontal Cortex, REM Sleep, Sleep Quality, Synaptic Plasticity.

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INTRODUCTION

Rapid Eye Movement (REM) sleep has increasingly been recognized as a critical stage in the consolidation of executive functions, a cluster of higher-order cognitive processes orchestrated by the prefrontal cortex (PFC). These functions include working memory, cognitive flexibility, inhibitory control, emotional regulation, and goal-directed decision-making, all of which are essential for adaptive behavior and psychological resilience. While the contribution of sleep to memory consolidation is well-documented, the specific role of REM sleep in enhancing executive functions has only recently garnered focused attention, revealing a nuanced and intricate relationship between neurophysiological sleep patterns and prefrontal cognitive integrity (1). The prefrontal cortex, a region central to executive functioning, is uniquely active during REM sleep—a phase marked by intense neuronal firing, increased cortical synchronization, and distinct neurochemical profiles, such as heightened acetylcholine levels. This heightened activity provides an optimal environment for synaptic plasticity, allowing the brain to refine, reorganize, and integrate neural circuits that are essential for executive control (2,3). Studies using functional magnetic resonance imaging (fMRI) have shown increased PFC activation following REM-rich sleep, correlating with improved outcomes on tasks requiring decision-making, attentional control, and emotional regulation (4). In parallel, the synaptic homeostasis hypothesis proposes that REM sleep facilitates both synaptic strengthening and pruning, processes that are indispensable for efficient cognitive processing and behavioral adaptability (5).

The detrimental effects of REM sleep deprivation further underline its cognitive relevance. Empirical data suggest that loss of REM sleep is associated with diminished activity in the PFC, leading to compromised decision-making abilities, reduced cognitive flexibility, and heightened emotional reactivity (6,7). These impairments have been linked to reduced modulation of the amygdala by the PFC, highlighting the importance of REM sleep in emotional regulation and stress response (7). Furthermore, disruptions to REM sleep adversely affect long-term plasticity mechanisms, weakening the consolidation of complex, higher-order cognitive functions (8,9). Emerging findings from neurophysiological studies employing optogenetics and electrophysiological recordings have demonstrated a bidirectional interaction between REM sleep and the medial prefrontal cortex (mPFC). Specifically, excitation of mPFC neurons during REM has been shown to regulate EEG theta oscillations—patterns known to support memory integration and cognitive coordination (10,11). In addition, REM sleep plays a key role in modulating emotional components of executive function through its regulation of the lateral hypothalamus and its connections to the PFC, helping mitigate negative emotional intensity and improving decision-making under conditions of psychological stress (12).

These findings highlight the broader implication of REM sleep in cognitive development and mental health. REM-associated reactivation of neural patterns allows the integration of new information with pre-existing knowledge, particularly in tasks involving problem-solving, strategic planning, and adaptability to novel challenges (13). Consequently, impaired REM sleep is increasingly viewed as a contributing factor to neuropsychiatric and neurocognitive disorders where executive dysfunction is a defining feature, such as depression, anxiety, attention-deficit/hyperactivity disorder (ADHD), and neurodegenerative diseases (14). Yet, despite these insights, a significant gap remains in fully understanding how REM sleep mechanistically supports the consolidation of specific executive functions. The neurochemical milieu of REM sleep—characterized by elevated acetylcholine and suppressed monoaminergic tone—has been proposed as a facilitator for the reorganization of cortical circuits, particularly those underpinning cognitive flexibility and inhibitory control (15). Moreover, REM's role in processing emotionally salient memories may underlie the observed improvements in emotional regulation and decision-making capacity, especially in high-stress scenarios (16). Disruptions to this process result in impaired adaptive responses and affective instability, underscoring REM's pivotal role in maintaining psychological homeostasis (17). Despite growing evidence, the neural pathways through which REM sleep supports PFC-mediated cognitive processing remain insufficiently mapped, limiting the development of effective interventions for sleep-related cognitive impairments. In light of this, the present study aims to investigate the neurocognitive mechanisms by which REM sleep contributes to the consolidation of executive functions. Specifically, it will examine the relationship between REM sleep and key executive processes including working memory, inhibitory control, and cognitive flexibility. Additionally, the study will evaluate the impact of REM sleep disruption on performance in executive function tasks and explore individual variability by considering factors such as age, stress levels, and baseline sleep quality. These objectives aim to deepen the understanding of REM's contributions to cognitive health and inform targeted strategies for cognitive enhancement and clinical intervention.

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METHODS

This cross-sectional, observational study was carried out between July and September 2024 and involved a sample of 145 Pakistani adults aged between 18 and 70 years. The sample size was determined using the WHO sample size calculator, applying a 5% margin of error and a 95% confidence level. Participants were selected using convenience sampling, which, while practical for exploratory studies, can limit the generalizability of findings due to potential selection bias. Ethical approval was granted by the Brain Tech Clinic and Research Centre (IRB number: BTC.2024.1998), and informed consent was obtained online from all participants prior to their inclusion in the study. Since all participants were over the age of 18, no parental or guardian consent was necessary. The study adhered strictly to the principles outlined in the Declaration of Helsinki and followed ethical standards for human research. Eligibility criteria included adults aged 18 to 70 years who provided informed consent and had no known history of neurological or psychiatric conditions. Individuals were excluded if they were currently on medication for sleep disorders, had a history of opioid misuse, or were previously diagnosed with sleep apnea or any other sleep-related pathology. These exclusion criteria ensured that sleep quality and executive function measurements were not confounded by underlying clinical conditions or pharmacological influences.

Data were collected using a self-administered structured questionnaire, consisting of four sections. The first section gathered demographic information, including age, gender, educational level, employment status, and marital status. The second section assessed sleep quality using the Pittsburgh Sleep Quality Index (PSQI), a validated tool designed to evaluate subjective sleep quality over a one-month interval. The PSQI comprises seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. Each component yields a score ranging from 0 to 3, with a cumulative global score ranging from 0 to 21. A global PSQI score of 5 or above was interpreted as poor sleep quality, whereas scores below 5 indicated good sleep quality (18). The PSQI demonstrates strong internal consistency with a reported Cronbach's alpha of 0.83 (19). The third section of the questionnaire focused on individualized accounts of REM sleep, aiming to capture qualitative and quantitative aspects of this specific sleep phase, although the method used for REM-specific assessment was not explicitly standardized, which could introduce subjectivity or variability in interpretation. The fourth section utilized the Frontal Assessment Battery (FAB) to evaluate executive functions primarily governed by the prefrontal cortex. The FAB includes six tasks that assess mental flexibility, inhibitory control, motor programming, conceptualization, sensitivity to interference, and environmental autonomy. Scores range from 0 to 18, with higher scores reflecting stronger executive functioning capabilities (20). Data analysis was performed using IBM SPSS Statistics for Windows, version 26.0. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were computed to summarize the demographic and categorical variables. The classification of PSQI components followed the methodology established by Smyth (21). The Shapiro-Wilk test was employed to assess the normality of continuous data distributions (22). Depending on the distribution characteristics, either Pearson's correlation (for normally distributed data) or Spearman's rank correlation (for non-normally distributed data) was used to explore the association between REM sleep quality and executive function performance. A p-value of less than 0.05 was considered statistically significant.

RESULTS

The analysis revealed significant relationships between demographic factors, sleep patterns, quality of life, and various cognitive and executive functioning measures. Gender differences were observed across several domains. Males represented 51% of the sample and females 49%. A statistically significant association was noted between gender and quality of life ($\chi^2 = 1.29$, $p = 0.01$), with 14% of males and 9% of females reporting excellent quality of life. No significant gender difference was found in sleep duration distribution ($p = 0.51$). Education level was significantly associated with both quality of life ($\chi^2 = 1.87$, $p = 0.00$) and sleep duration ($\chi^2 = 1.86$, $p = 0.01$). Participants with bachelor's degrees (53%) more frequently reported better quality of life and longer sleep duration. Employment status was also associated with quality of life ($\chi^2 = 2.39$, $p = 0.04$) but not with sleep duration ($p = 0.71$). Unemployed individuals reported a higher rate of excellent quality of life (15%) than employed participants (8%). Marital status showed no significant link to quality of life ($p = 0.92$), although sleep duration distribution varied significantly between married and single individuals ($p = 0.00$). Age significantly influenced quality of life ($\chi^2 = 7.27$, $p = 0.00$) but not sleep duration ($p = 0.96$). Young adults and old adults most frequently reported excellent quality of life.

Pearson correlation analysis demonstrated a strong positive relationship between sleep duration and quality of life ($r = 0.452$, $p < 0.01$), while stress showed a negative correlation with both quality of life ($r = -0.387$, $p < 0.01$) and sleep duration ($r = -0.182$, $p < 0.05$). Cognitive failures negatively correlated with quality of life ($r = -0.317$, $p < 0.01$) and positively with stress ($r = 0.306$, $p < 0.01$). Frontal

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cortex functioning was not significantly associated with quality of life or sleep duration but had a significant negative relationship with cognitive failures ($r = -0.306$, $p < 0.01$). Independent samples t-tests revealed gender differences in cognitive domains. Females reported significantly more cognitive failures ($M = 33.12$, $SD = 19.21$) compared to males ($M = 29.63$, $SD = 14.40$; $p = 0.01$), with higher distractibility ($p = 0.00$) and false triggering scores ($p = 0.00$). Stress levels were also higher in females ($M = 5.70$, $SD = 2.55$) than males ($M = 4.88$, $SD = 2.50$; $p = 0.05$). Frontal lobe function was marginally higher in females ($p = 0.03$). Employment status impacted frontal lobe function significantly ($p = 0.02$), favoring employed individuals, but not cognitive failures or stress. Marital status also influenced frontal lobe function ($p = 0.02$), with single individuals scoring higher. Married participants exhibited significantly higher stress ($p = 0.05$), although no other variables differed significantly. Age-related analysis using ANOVA revealed a significant difference in stress across age groups ($F = 3.84$, $p < 0.05$, $\eta^2 = 0.08$), with senior adults experiencing the highest stress. No significant age-based differences were observed in cognitive failures, frontal lobe function, or related cognitive domains.

Sleep duration had a notable impact on cognitive and emotional functioning. Individuals sleeping less than 5 hours reported the highest stress ($M = 7.18 \pm 3.19$), cognitive failure ($M = 57.00 \pm 23.59$), forgetfulness ($M = 16.45 \pm 7.13$), distractibility ($M = 18.27 \pm 7.23$), and false triggering ($M = 15.09 \pm 6.82$). ANOVA results confirmed significant group differences for stress ($F = 2.63$, $p < 0.05$), cognitive failure ($F = 4.95$, $p < 0.05$), forgetfulness ($F = 2.85$, $p < 0.05$), and false triggering ($F = 3.12$, $p < 0.05$). Participants who slept between 7–8 hours displayed the highest frontal lobe function ($M = 11.03 \pm 1.98$), although the overall difference was not statistically significant ($F = 2.64$, $p = 0.056$). Quality of life was significantly associated with all cognitive and stress-related variables. Participants with poor quality of life had the highest stress ($M = 7.10 \pm 2.34$) and cognitive failure scores ($M = 30.22 \pm 17.13$). In contrast, those with excellent quality of life showed the lowest levels of stress ($M = 4.09 \pm 2.61$) and cognitive failures ($M = 24.53 \pm 10.74$). Statistically significant differences were also found in forgetfulness ($F = 6.63$, $p < 0.05$), distractibility ($F = 4.07$, $p < 0.05$), and false triggering ($F = 3.77$, $p < 0.05$), all of which were lowest in the excellent quality of life group.

Table 1: Quality of life and sleep duration by demographic variables

Variables	**f(%)**	**Quality of life**				**χ^2**	**p**	**Sleep Duration**					**χ^2**	**-**
-	-	Poor	Fair	Good	Excellent	-	-	Less than 5 hours	5-6 hours	6-7hours	7-8hours	More than 8hours	-	P
Gender	-	-	-	-	-	-	-	-	-	-	-	-		-
Male	74(51)	10	19	30	14	1.29	0.01	4	28	20	18	4	3.34	0.51
Female	71(49)	10	22	30	9			7	26s	14	16	8		
Education	-	-	-	-	-	-	-	-	-	-	-	-		-
High school	54(37)	7	13	23	11	1.87	0.0	4	20	13	12	5	1.86	0.01
Bachelors	78(53)	12	24	32	10			5	29	18	20	6		
Other	13(9)	2	4	5	2			2	5	3	2	1		
Employment	-	-	-	-	-		-	-	-	-	-	-		-
Employed	44(30)	9	11	16	8	2.39	0.04	4	19	9	10	2	2.10	0.71
Unemployed	101(69)	12	30	44	15			7	35	25	24	10		
Marital Status	-	-	-	-	-	-	-	-	-	-	-	-		-
Single	137(95)	20	38	57	22	0.37	0.92	10	51	32	32	12	0.99	0.00
Married	8(5)	1	3	3	1			1	3	2	2	0		
Age	-	-	-	-	-	-	-	-	-	-	-	-		-
Young adults	42(29)	9	13	12	8	7.27	0.0	4	13	11	10	4	4.93	0.96
Middle adults	1(0.7)	0	0	1	0			0	0	1	0	0		
Old adults	98(67)	11	27	46	14			7	39	21	23	8		
Senior old adults	**4(2.8)**	**1**	**1**	**1**	**1**			**0**	**1**	**2**	**1**	**0**		

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Table 2: Correlations between sleep duration, stress, cognitive failures, and frontal cortex functioning

Variables	1	2	3	4	5	6	7	8	9
Gender	-	-	-	-	-	-	-	-	-
Quality of Life	-.058	-	-	-	-	-	-	-	-
Sleep Duration	-.002	0.452**	-	-	-	-	-	-	-
Stress	.164*	-0.387**	-0.182*	-	-	-	-	-	-
Cognitive Failure	.034	-0.317**	-0.007	0.306**	-	-	-	-	-
Frontal Cortex functioning	.071	0.161	0.050	-0.080	-0.306**	-	-	-	-
Forgetfulness	.170*	-0.284**	-0.029	0.308**	0.911**	-0.160	-	-	-
Distractibility	.285**	-0.158	-0.008	0.329**	0.906**	-0.178*	0.779**	-	-
False Trigging	.236**	-0.182*	-0.059	0.274*	0.871**	-0.232**	0.841**	0.763**	-

Table 3: Gender, differences in cognitive performance, stress, and frontal lobe functioning

Gender Difference							
-	Male	Female	-	-	-	CI95%	-
Variable	Mean(±SD)	Mean(±SD)	T	P	Cohens d	LL	UL
Frontal Lobe Function	10.30 (±2.65)	10.68 (±2.68)	-0.965	0.03	0.14	-1.25	0.49
Forgetfulness	10.61 (±5.40)	10.61 (±5.40)	-0.855	0.39	0.37	-4.74	-0.51
Cognitive Failure	29.63 (±14.40)	33.12 (±19.21)	-2.457	0.01	0.18	-3.71	0.42
Distractibility	11.28 (±5.50)	15.42 (±7.58)	-3.776	0.00	0.53	-6.30	-1.97
False Trigging	8.19 (±5.12)	11.08 (±6.57)	-2.967	0.00	0.44	-4.82	-0.96
Stress	4.88 (±2.50)	5.70 (±2.55)	-1.968	0.05	0.32	-1.65	0.003

SD=Standard Deviation, t=t-value from the independent samples t-test. P=level of significance, 95%CI= 95% Confidence Interval, LL= Lower Limit and UL= Upper Limit, independent samples t-tests were used, and significance was set at $p < 0.05$, **=p<0.01, **=p<0.05.

Table 4: Comparison of Cognitive Performance, Frontal Lobe Functioning, and Stress Levels by Employment and Marital Status

Employment							
-	Unemployed	Employed		-	-	95%CI	
Variable	Mean(±SD)	Mean(±SD)	T	P	Cohens d	LL	UL
Cognitive Failure	31.25 (±16.51)	30.27 (±16.34)	0.25	0.0	0.80	-6.69	8.64
Frontal Lobe Function	10.64 (±2.74)	10.11 (±2.48)	1.10	0.02	0.22	-0.42	1.48
Forgetfulness	11.72 (±6.50)	12.30 (±6.75)	-0.48	0.03	0.08	-2.92	1.77
Distractibility	13.14 (±7.07)	13.70 (±6.54)	-0.45	0.65	0.05	-3.03	1.90
False Trigging	9.59 (±5.99)	9.64 (±6.20)	-0.03	0.01	0.00	-2.20	2.12
Stress	5.12 (±2.64)	5.66 (±2.31)	-1.17	0.24	0.15	-1.45	0.37
Marital Status							
	Single	Married				95%CI	
Variable	Mean(±SD)	Mean(±SD)	T	P	Cohens d	LL	UL
Cognitive Failure	31.07 (±16.79)	29.00 (±7.04)	0.27	0.78	0.15	-13.0	17.1
Frontal Lobe Function	10.54 (±2.66)	9.50 (±2.73)	1.07	0.02	0.22	-0.87	2.95
Forgetfulness	11.87 (±6.62)	12.38 (±5.76)	-0.21	0.83	-0.07	-5.24	4.22
Distractibility	13.31 (±6.94)	13.38 (±6.44)	-0.02	0.00	-0.01	-5.04	4.91
False Trigging	9.50 (±5.92)	11.50 (±7.91)	-0.9	0.01	-0.20	-6.34	2.34
Stress	5.20 (±2.55)	6.75 (±2.31)	-1.68	0.05	-0.39	-3.38	0.27

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Table 5: Age-related differences in stress, cognitive failures, and executive functions

Measure	Young adults	Middle adults	Old Adults	Senior old adults	F(3,141)	η^2
-	Mean(±SD)	Mean(±SD)	Mean(±SD)	Mean(±SD)	-	-
Stress	6.07 (±2.72)	0.00 (±0.00)	4.95 (±2.37)	6.50 (±2.38)	3.84*	0.08
Cognitive Failure	30.00 (±19.25)	25.00 (±0.00)	31.30 (±15.67)	33.33 (±12.70)	0.10	0.00
Frontal Lobe Function	10.45 (±2.62)	8.00 (±0.00)	10.56 (±2.72)	9.50 (±2.08)	0.50*	0.01
Forgetfulness	13.26 (±7.21)	8.00 (±0.00)	11.36 (±6.32)	11.75 (±4.57)	0.95*	0.02
Distractibility	13.98 (±7.59)	8.00 (±0.00)	13.08 (±6.75)	13.25 (±2.06)	0.36	0.01
False Trigging	10.21 (±7.00)	8.00 (±0.00)	9.41 (±5.70)	8.50 (±3.87)	0.24*	0.00

M=mean, SD=standard deviation, η^2=effect size.

Table 6: Sleep duration and its effects on stress, cognitive failures, and executive functions

Measure	Less than 5 hours	5-6 hours	6-7hours	7-8hours	More than 8hours	F(3,141)	η^2
-	Mean(±SD)	Mean(±SD)	Mean(±SD)	Mean(±SD)	Mean(±SD)	-	-
Stress	7.18 ± 3.19	5.35 ± 2.56	4.68 ± 2.36	4.88 ± 2.10	6.08 ± 2.91	2.63*	0.058
Cognitive Failure	57.00 ± 23.59	26.21 ± 14.72	35.92 ± 15.89	30.32 ± 14.76	23.14 ± 6.31	4.95*	0.145
Frontal Lobe Function	9.18 ± 3.46	10.91 ± 2.74	9.53 ± 2.80	11.03 ± 1.98	10.92 ± 2.07	2.64	0.056
Forgetfulness	16.45 ± 7.13	10.46 ± 6.34	13.53 ± 6.24	10.91 ± 5.22	12.33 ± 9.05	2.85*	0.061
Distractibility	18.27 ± 7.23	11.93 ± 7.01	13.62 ± 5.69	13.41 ± 6.10	13.83 ± 9.72	2.06	0.04
False Trigging	15.09 ± 6.82	8.50 ± 5.61	10.29 ± 5.65	8.94 ± 5.36	9.50 ± 7.83	3.12*	0.06

M=mean, SD=standard deviation, η^2=effect size.

Table 7: Quality of life and its impact on stress, cognitive failures, and executive functions

Measure	Poor	Fair	Good	Excellent	F(3,141)	η^2
-	Mean(±SD)	Mean(±SD)	Mean(±SD)	Mean(±SD)	-	-
Stress	7.10 ± 2.34	6.05 ± 2.24	4.58 ± 2.34	4.09 ± 2.61	9.33*	0.19
Cognitive Failure	30.22 ± 17.13	41.88 ± 17.03	26.87 ± 14.77	24.53 ± 10.74	6.05	0.130
Frontal Lobe Function	10.33 ± 2.83	9.98 ± 2.89	10.52 ± 2.67	11.43 ± 1.83	1.52	0.033
Forgetfulness	13.10 ± 7.75	15.15 ± 5.66	9.97 ± 6.21	10.04 ± 5.49	6.63*	0.126
Distractibility	14.00 ± 8.30	16.05 ± 6.52	11.38 ± 6.15	12.83 ± 6.71	4.07*	0.087
False Trigging	10.10 ± 7.94	12.02 ± 5.51	8.30 ± 5.74	8.26 ± 4.42	3.77*	0.075

M=mean, SD=standard deviation, η^2=effect size.

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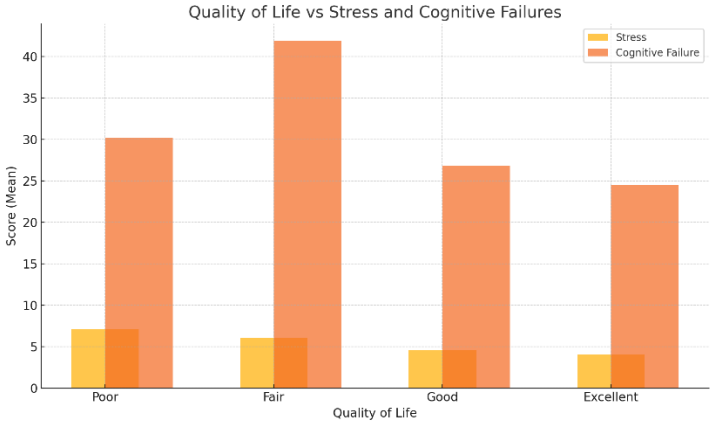


Figure 1 Quality of life vs Stress and Cognitive Failures

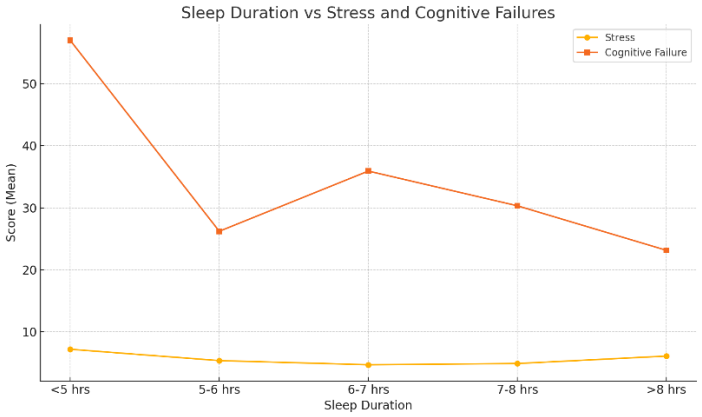


Figure 2 Sleep Duration vs Stress and cognitive Failures

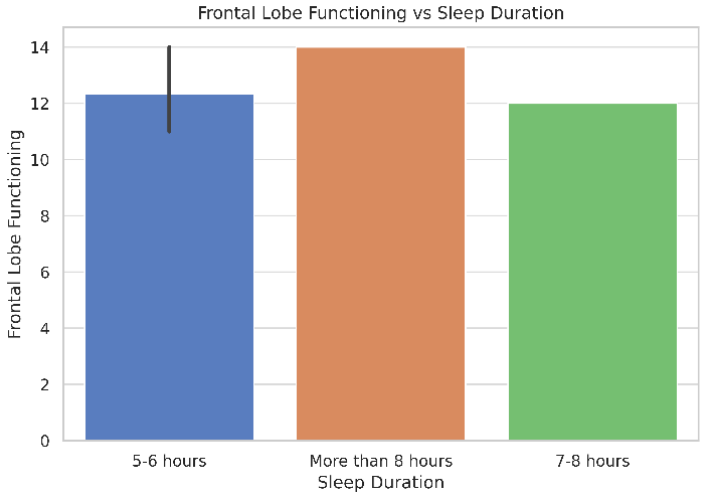


Figure 3 Frontal Lobe Functional vs Sleep Duration

DISCUSSION

The present study explored the role of REM sleep quality in facilitating executive functions—namely working memory, inhibitory control, and cognitive flexibility—through the functional lens of the prefrontal cortex (PFC). The findings contribute to a growing body of literature underscoring the importance of REM sleep in supporting higher-order cognitive processes. Participants with better overall sleep quality, particularly those reporting 7–8 hours of sleep, showed significantly improved performance in tasks governed by the PFC, as measured by the Frontal Assessment Battery. This supports the neurobiological premise that REM sleep plays a pivotal role in optimizing executive performance by fostering synaptic plasticity and neural reorganization (15,16). These results align with the synaptic homeostasis hypothesis, which posits that sleep—particularly REM—facilitates the downscaling of synapses while preserving those that are functionally significant. This mechanism is believed to enhance the brain's ability to integrate new information with existing cognitive frameworks. Participants with longer and higher-quality sleep appeared to benefit from this neural optimization, performing better in domains such as cognitive flexibility and working memory. Conversely, individuals with sleep durations below five hours demonstrated significantly higher levels of cognitive failures, forgetfulness, and distractibility, suggesting diminished PFC efficiency due to insufficient REM sleep (17). The impairment of stress regulation in these individuals further supports the concept that REM sleep contributes to emotional modulation through effective PFC-amygdala connectivity (18).

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The gender-based differences observed in this study revealed that females reported greater cognitive lapses and higher stress levels than males. These findings resonate with previous literature suggesting that hormonal fluctuations and sociocultural stressors may heighten vulnerability to the cognitive and emotional consequences of poor sleep in women (19,20). Age-related differences, though modest, indicated a gradual decline in executive performance among older adults, which may be attributed to the natural attenuation of both PFC functionality and REM-rich sleep stages with advancing age (21). Psychosocial variables also played a moderating role. Employed individuals and those who were single demonstrated better frontal lobe functioning and lower stress levels compared to their counterparts. These findings suggest that cognitive engagement and reduced emotional burdens may promote more resilient executive functioning. Such patterns are consistent with existing cognitive load theories, which propose that stable environmental and occupational structures may preserve cognitive resources by minimizing emotional interference (22).

A notable strength of the study lies in its multidimensional assessment of executive functions, sleep quality, and emotional well-being within a diverse adult population. The use of validated instruments such as the Pittsburgh Sleep Quality Index and Frontal Assessment Battery added methodological rigor. Additionally, the exploration of moderating variables such as gender, age, employment, and marital status enhances the ecological validity of the findings. However, the study is not without limitations. A key concern is the reliance on self-reported sleep data, which may be subject to recall bias and misclassification. The absence of objective physiological measurements, such as polysomnography, limits the accuracy of REM sleep quantification. This constraint may have diluted the precision of the associations between REM sleep and specific executive outcomes. Furthermore, the cross-sectional design precludes causal inference, restricting the ability to determine whether impaired sleep leads to cognitive dysfunction or vice versa. While significant associations were observed, longitudinal or interventional studies are warranted to validate the temporal dynamics of REM-related cognitive consolidation.

Future research should prioritize objective sleep monitoring techniques to isolate the REM phase and its neural correlates more accurately. Incorporating neuroimaging modalities such as fMRI or EEG would provide deeper insights into the functional activation patterns of the PFC in relation to sleep architecture. Moreover, exploring these relationships in clinical populations with known sleep disturbances or cognitive impairments, such as individuals with anxiety disorders or neurodegenerative diseases, may yield clinically relevant applications. In conclusion, the findings underscore REM sleep's integral role in maintaining executive functions through its effect on the prefrontal cortex. While supporting existing theories of sleep-mediated neuroplasticity, the study highlights important demographic and psychosocial moderators that influence cognitive resilience. Though the evidence is compelling, methodological enhancements and longitudinal approaches will be essential to advance the understanding of REM sleep as a neurocognitive regulator.

CONCLUSION

This study concludes that REM sleep plays a pivotal role in supporting executive functions regulated by the prefrontal cortex, particularly cognitive flexibility, working memory, and emotional regulation. Individuals with sufficient REM sleep exhibited stronger executive performance, while those with disrupted sleep patterns showed noticeable cognitive and emotional impairments. These outcomes emphasize the necessity of prioritizing healthy sleep practices across the lifespan, especially during critical developmental stages such as adolescence. The findings suggest that enhancing REM sleep through targeted interventions could offer a practical approach to improving cognitive resilience and managing stress-related impairments in executive function.

AUTHOR CONTRIBUTION

Author	Contribution
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Syed Mughees Hussain Shah	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
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