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Original Article

Physiology Section

The Impact of Disrupted Sleep Schedules on Frontal Lobar Executive Functioning, Cognitive Flexibility, Inhibitory Control and Autonomic Reactivity among Nursing Students: A Cross-sectional Study

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ABSTRACT

Introduction: Disrupted sleep schedules particularly in night shift workers like nurses are known to impair attention and psychomotor performance, however its impact on frontal lobe executive function, inhibitory control and autonomic reactivity to a cognitive load remain highly unexplored.

Aim: To evaluate the influence of 12 hours of sleep deprivation due to night shift work on sleep quality, cognitive flexibility, inhibitory control, and autonomic reactivity and frontal lobe functions among nurses, and compare their findings with the day shift working nurses of a tertiary hospital.

Materials and Methods: A cross-sectional study was conducted from August 2021- April 2022 on 72 nursing students out of which 36 were working night shifts at a KLE'S Prabhakar Kore tertiary care hospital and MRC, Belgaum, Karnataka, India and 36 serving as daytime controls. The Pittsburgh Sleep Quality Index (PSQI) was used to assess sleep quality. Iowa Trail Making Test (ITMT), Frontal Assessment Battery (FAB) and computerised Go-NO Go test were administered to measure visual scanning, attention, cognitive flexibility, executive functions, and inhibitory control. For autonomic reactivity heart rate and blood pressures (SBP and DBP) were measured at baseline as well as during Go/No-Go task (Cognitive stressor). Group comparisons were performed using Student's t-test and One-way Analysis of Variance (ANOVA).

Results: The groups were comparable in age (21.1±1.97 years vs 21.2±2.01 years; p-value=0.64) and gender distribution. Baseline heart rate and blood pressure values did not differ significantly between the groups (p-value>0.05). Shift workers had poor sleep quality with higher scores (19±2.1) on the PSQI, compared to controls. ITMT completion times were significantly prolonged for shift workers on both part A (27±8.9 vs 19±4.2, p-value=0.001) and part B (176±7.54 vs 101±5.55, p-value =0.04). The FAB scores was significantly lower in shift workers (12.21±0.4) compared to controls (18.±0.9, 180.24, p-value =0.004).

Conclusion: Night shift nurses experience poor sleep quality, impairments in frontal executive functions, disinhibition, and heightened sympathetic reactivity increasing cognitive errors in safety-critical clinical settings. Evidence based duty roster and sleep schedules are therefore essential from an occupational health point of view.

Keywords: Autonomic nervous system, Blood pressure, Executive functions, Night shifts, Sleep deprivation

INTRODUCTION

Sleep is an active reversible state of unconsciousness necessary for bodily restoration and cognitive health [1]. It is regulated primarily by Circadian rhythms which are controlled by suprachiasmatic nucleus of hypothalamus and synchronised by environmental cues transmitted through the retino-hypothalamic tract. Sleep wake cycle transitions are modulated by ascending reticular system, dorsal raphe, ventral tegmental area, locus coeruleus, and latero-dorsal tegmental and pedunculopontine nuclei to maintain alertness and arousal [2].

Adequate sleep is optimal for cognitive processes such as attention, memory consolidation, executive control and decision making. Conversely sleep deprivation disrupts circadian regulation and has been associated with reduced mental alertness, memory deficits, diminished logical reasoning and sub optimal decision making [3,4]. In healthcare settings, shift work and night duties are unavoidable, particularly in fields like nursing which require continuous patient care. In nursing, where non-standard working hours are essential for uninterrupted patient care and managing critically ill individuals, shift workers often sacrifice their sleep. Research indicates that sleep related cognitive decline increases significantly with consecutive night shifts and because of fatigue there is a 6% decline on the second night, 17% third night, and a striking 36% on fourth night and these transcend into execution errors especially medical administration errors [5-7].

Altered circadian rhythm causes these sleep deprived nursing staff to remain awake during the circadian nadir and sleep during biological daytime by disregarding environmental cues that promote wakefulness, leading to reduced sleep duration and build-up of sleep debt and ultimately impaired cognitive and frontal lobe functions [8]. Previous research has shown that this circadian desynchronisation can result in a decrease in global activation patterns, particularly in bilateral prefrontal and parietal circuits, leading to impulsivity, lowered attention, lowered frontal lobe functions like response inhibition affecting cognitive control as well as behaviour [9,10].

Despite growing evidence linking sleep disruption and cognitive functioning, limited studies have comprehensively evaluated the combined effects of sleep quality, cognitive flexibility and frontal lobe functions especially inhibitory control using neuropsychological tools in nursing students exposed to night duty schedules [11,12], So, it was hypothesised that sleep deprivation will result in significant impairment in sleep quality, functions of the frontal lobe

like conceptualisation, impulse control and autonomic reactivity compared to well rested (day shift) conditions while the null hypothesis stated that night shift work has no significant effect on all the above as compared with day shift conditions.

With this background, the present study was conducted to examine the impact of sleep deprivation on sleep quality, cognitive flexibility, inhibitory control, frontal lobe executive functions and autonomic reactivity among the nursing students, a critical cognitive function required for multitasking and safe patient care using standardised subjective sleep quality questionnaire and computer based cognitive assessments.

MATERIALS AND METHODS

This cross-sectional study was conducted during the period August 2021- April 2022 at a tertiary hospital KLE'S Prabhakar Kore hospital and MRC, Belgaum, Karnataka, India. The study obtained clearance from the Institutional Ethics Committee on Human Subjects Research (IEC no: MDC/DOME/77). Participants were explained of the study's purpose, and their voluntary informed written consent was obtained prior to the study commencement. Confidentiality of the data was maintained throughout the study and the participants were assured of their right to withdraw from the study without any academic consequences.

Inclusion criteria: Nurses aged between 21-23 years (36 females and 36 males) who were engaged in hospital night shift duties (working for consecutive 4 nights/ week, from 8 pm- 8 am (12 hours) were included as cases. Age and gender matched day shift working nurses with no history of regular night shifts during the same period were included as controls.

Exclusion criteria: Nurses, who had visual or hearing deficits, had history of muscular disorders, with history of diabetes or any major medical illness, alcohol consumption or tobacco use in any form, psychiatric illness or on any sleep related medications were excluded from the study.

Sample size:

Expected reduction-(mean)=d=13.4

SD=σ=48; Power=80%; α error= 0.05 [13];

One-sided Zα=1.65 and β error=0.2; n={(Zα+Zβ) σ/d2}=71.64=72

The study included 72 (4th year) Nursing students (age 21-23 years) 36 females and 36 males. Of these 36 participants were doing night shift duties at tertiary care hospital (8 PM-8 AM) and remaining 36 acted as age and gender matched control working day shifts.

Data Collection Tools

1) Sleep schedule compliance was assessed using the PSQI [14], a widely recognised tool for evaluating adult sleep quality. Comprising 19 items, it gauges various sleep aspects like duration, disturbances, latency, daytime dysfunction, and subjective quality. Each item scores from 0 to 3, with a total range of 0 to 21, higher scores suggesting poorer sleep quality. The PSQI assists in identifying individuals with sleep-related issues, aiding both researchers and clinicians.
2) The ITMT assessed cognitive flexibility, visual scanning, and attention [15]. This attention assessment comprises two parts: Part A involves connecting numbers sequentially with a continuous line, gauging visual search, complex visual scanning, and speed of visual-spatial processing. Part B combines numbers and letters, testing set shifting, alternate attention, and mental flexibility. The aim is swift completion of both parts, with scores based on total time taken. Scoring: Each part (A and B) was timed in seconds from the start of the test till its completion where the participant had to complete the trail, errors were permitted to be corrected on the spot and total time in seconds recorded for both the parts. Interpretation: Higher completion time in seconds indicated poor performance. The Part A (IMT-A): tests for visual scanning and processing speed while Part B (IMT-B): tests for cognitive flexibility, set shifting, attentional switching.
3) FAB evaluated frontal lobe functions [16]: It is a cognitive screening tool targeting executive functions associated with frontal lobes. With six subtests, it assesses planning, reasoning, cognitive flexibility, and inhibitory control. Tasks involve word generation, instruction following, and motor control demonstration, conceptualisation, mental flexibility, motor programming, interference sensitivity, inhibitory control, and environmental autonomy. The following six subtests: (1) to evaluate abstract and conceptual thinking questions about the similarities between two objects were asked; (2) to assess verbal fluency and mental flexibility, the participant had to list as many words as possible starting with a specific letter within 1 min; (3) questions asking individuals to perform the Luria manoeuvre and fist-edge-palm patterns to determine if their programming and motor acts were correctly executed; (4) to assess sensitivity and interference, questions requesting the participants to provide an opposite response to the examiner's signals (conflicting instructions); (5) to assess inhibitory control, asking the participants to inhibit their response to a stimulus that was previously administered (go-no-go test) and (6) questions assessing the involuntary behaviour that is triggered by sensory stimulation to detect deficits in the environmental autonomy. The battery takes about 10 minutes, subtests have a valued marking (from zero, completely wrong subtest; to three, completely correct subtest). The final score is the sum of the six subtests (with values ranging from 0 to 18), and the higher the score, the better is the frontal functioning.
4) The Go No-Go paradigm from Frontal assessment battery (FAB) [16]: Used to measure impulsivity and response inhibition. The test detects the ability to inhibit habitual responses which requires an effort and brain to process the signals and can measure anxiety. Testable software was used to conduct the test. It uses blue and yellow boxes as No Go and Go stimuli. If a yellow square appears on screen the participants must press the p key on the desktop and nothing at all if the blue square appears on screen. There will be many Go stimuli to make the participants feel habituated. A go trial is considered successful when a participant responds within a time window while No Go trial is considered successful when a participant does not respond at all. In each trial the Go- and No-Go stimuli will be shown for a brief period (1 second) and the participants need to either respond or not [Table/Fig-1].

Variable	Definition
Total true score	True hits on Go and No- Go trials
Hit	True Hits on Go trials
Stop	True inhibition on No- Go trials
Omission error	Missed go trials
Commission error	False hits on No-Go Trials (Disinhibition)
Reaction time of Hits	Reaction time of true Go trials in ms
Reaction time of Stops	Reaction time of false No- Go trials in ms

[Table/Fig-1]: Parameters for go/no go test.

Study Procedure

A total of 72 nursing students participated, with 36 assigned to night shifts from 8 pm to 8 am; the rest had morning shifts. The participants were asked to refrain from caffeine and alcohol for at least 24 hours prior to and during the study period and limit their excessive screen exposure. The day shift controls were required to maintain a regular sleep duration of 7-9 hours of sleep per night. Data collection was conducted daily following completion of post-

night shifts for study participants. Participants first completed the PSQI to assess subjective sleep quality (average time: 10 min), including baseline heart rate and blood pressure recorded using semi-automated omni sure sphygmomanometer. Subsequently cognitive and executive functions were assessed using FAB (15 min), the ITMT to assess attention, cognitive flexibility, and visual-spatial processing (20 min). Finally, response inhibition and impulsivity were assessed using computer-based Go/No -Go task administered using testable software (15 min). Continuous recording of heart rate and blood pressure was performed during the Go/No-Go task to assess autonomic physiological responses elicited by cognitive load.

STATISTICAL ANALYSIS

Data was entered onto a Microsoft excel sheet and analysed using Statistical Package for the Social Sciences (SPSS) version 31.0. Continuous variables were quantified as Mean±Standard Deviation. The unpaired student's t-test was used to compare the intergroup differences between night shift and day shift participants. One-way ANOVA test was employed to evaluate the effect of group (shift workers vs controls) on cognitive tasks like ITMT part A and B, FAB battery. The p-value was considered significant <0.05.

RESULTS

Demographic characteristics: The study included 36 nursing shift workers and 36 day-shift controls (mean age: 21 years; equal male-to-female ratio). Demographic characteristics, including age, gender distribution, heart rate, and blood pressure, were comparable between nursing shift workers and day-shift controls. Nursing shift workers demonstrated significantly poorer sleep quality, with higher PSQI scores (19±2.1) compared to day-shift controls (7±0.11; p-value<0.001) [Table/Fig-2].

Variables	Shift workers	Controls	p-value
Age (years)	21.1±1.97	21.2±2.01	0.64
Gender (M:F)	18:18	18:18	1
Heart rate (Beats/min)	82±3.33	78±2.8	0.12
Blood Pressure (mmHg)	Systolic-112±4.61	Systolic-110±3.89	0.954
	Diastolic-80±5.01	Diastolic-72±6.17	0.052
PSQI scores	19±2.1	7±0.11	<0.001*

[Table/Fig-2]: Sociodemographic details of participants.
*p-value <0.05 was considered as statistically significant

Attention and Cognitive Flexibility (Iowa Trail Making Test): Shift workers performed significantly worse on the ITMT compared to controls. In Part A, shift workers required more time to complete the task (27±8.9) than controls (19±4.2; p-value<0.05). In Part B, shift workers also showed slower performance (176±7.54) compared to controls (101±5.55; p-value<0.05), indicating significantly poorer attention and reduced cognitive flexibility [Table/Fig-3].

Part	Shift workers (n=36)	Controls (n=36)	p-value
A (seconds)	27±8.9	19±4.2	0.001*
B (seconds)	176±7.54	101±5.55	0.04*

[Table/Fig-3]: Comparison of Iowa Trail Making Test (ITMT) among shift workers and controls.
*p-value <0.05 was considered as statistically significant

Response Inhibition and Impulsivity (Go-No Go Test): Controls achieved higher overall scores compared to shift workers (p-value=0.001). Shift workers exhibited a greater number of omission errors (19.8±9.91 vs 14.24±12.09; p-value=0.001) and significantly more commission errors, or false responses on No-Go trials (77.84±11.7 vs 69.09±9.88; p-value=0.04) [Table/Fig-4]. Reaction time for Stops was shorter among shift workers (71.81±11.04) compared to controls (80.66±12.01; p-value=0.001), suggesting greater impulsivity. Reaction time for hits did not differ significantly between groups (p-value=0.460) [Table/Fig-5].

	Overall score	Go Trials score		No-Go Trial score	
		Hits %	Omission error%	Stops%	Commission error%
Shift workers	77.3±9.02	73.84±11.7	19.8±9.91	70.31±9.6	70.84±11.7
Controls	89±14.5	84.21±13.9	14.24±12.09	76.01±11.34	69.09±9.88
p-value	0.001*	0.9	0.001*	0.01	0.04*

[Table/Fig-4]: Comparison of go-no go test values among shift workers and controls.
*p-value <0.05 was considered as statistically significant

	Shift workers (n=36)	Controls (n=36)	p-value
Reaction time hits (ms)	80.02±14.62	76.22±12.22	0.460
Reaction time of stops (ms)	71.81±11.04	80.66±12.01	0.001*
Heart rate during the test (beats/min)	90.01±17.50	82±15.66	0.04*
Blood pressure during the test (mmHg)	Systolic-124±12.33	Systolic-122±11.45	0.761
	Diastolic-88±11.76	Diastolic-76±10.08	0.002*

[Table/Fig-5]: Comparison of reaction times and autonomic reactivity during go/no-go test among shift workers and controls.
*p-value <0.05 was considered as statistically significant

Autonomic responses during Go-No Go Test: During the Go-No Go Test, heart rate was significantly higher in shift workers (90.01 ±17.50 bpm) compared to controls (82±15.66 bpm; p-value=0.04). Differences in systolic blood pressure were not significant but diastolic blood pressure between the two groups was statistically significant (88±11.76 mmHg) while controls (76±10.08 mmHg) [Table/Fig-5].

Executive function (Frontal Assessment Battery): On the FAB, shift workers scored significantly lower overall (12.21±0.4) compared to controls (18±0.9; p-value=0.004). Subdomain analysis revealed significant impairments in comprehension p-value <0.001, motor speed (p-value=0.004), sensitivity to interference (p-value=0.002*), inhibitory control (p-value=0.0001), and environmental autonomy (p-value=0.0004). No significant differences were observed in Lexical fluency [Table/Fig-6].

Frontal Assessment Battery (FAB) Sub domains	Shift workers (n=36)	Controls (n=36)	p-value
a) Similarities/comprehension/abstract reasoning	2.0±0.6	3±0.8	<0.001*
b) Lexical fluency/mental flexibility	2.0±0.7	3±0.6	0.2
c) Motor programming/speed	2.0±0.5	3±0.4	0.004*
d) Conflicting instructions/sensitivity to interference	2.0±0.4	3.0±0.6	0.002*
e) Go/ No-Go/inhibition	2.0±0.7	3.0±0.5	0.0001*
f) Prehension/Environmental autonomy	2.0±0.6	3.0±0.4	0.0004*
Total Global Score	12±0.4	18±0.9	0.004*

[Table/Fig-6]: Comparison of Frontal Assessment Battery (FAB) scores among shift workers and controls.
*p-value <0.05 was considered as statistically significant

DISCUSSION

The present study examined the impact of night shift related sleep deprivation on sleep quality and multiple cognitive domains with emphasis on attention, cognitive flexibility, execution, response inhibition as well as autonomic reactivity among nursing students engaged in night duties with age and gender matched day shift controls. The findings demonstrate a significant deterioration in the sleep quality among the night shift workers marked by higher PSQI scores (19±2.1), compared to the day shift controls (7±0.11) These results align with existing literature reporting fragmented

sleep, reduced sleep duration and poor subjective sleep quality among shift workers attributed to circadian maladjustments created between endogenous biological rhythms and external cues [17].

Circadian desynchronisation impairs the restorative function of sleep and adversely affects higher order cognitive processes mediated by frontal and parietal cortical networks [18]. In the present study, beyond impaired sleep quality, night shift nurses demonstrated significant deficits across multiple domains. While Part A suggests visual scanning and psychomotor speed, Part B suggests task switching, executive function and working memory. The substantially higher effect sizes especially in part B suggest executive functions being more affected by night shifts. Prolonged completion times on both ITMT (Part A- 27±8.9 and Part B- 176±7.54) compared to controls (Part A- 19±4.2 and Part B- 101±5.55) suggest impairments in visual scanning, divided attention and set shifting abilities. These findings reflect decreased efficiency in mental processing speed, higher commission rates, and reduced inhibition among shift workers [19].

Physiologically the pre-frontal cortex and parietal cortices are functionally connected and highly susceptible to circadian alterations and fatigue, which may translate into diminished situational awareness and compromised multitasking and delayed responses patient as well as equipment cues thereby increasing risk of clinical errors.

The performance on FAB revealed a reduction in the total scores (12±0.4) in night shift nurses as compared to (18±0.9) their day time controls, indicating a compromised abstract reasoning, motor programming sensitivity to interference, response inhibition, cognitive prehensive behaviour. These findings are consistent with previous studies demonstrating that sleep deprivation disrupts attention, working memory and executive control often manifest as a speed accuracy trade off [20,21]. While individuals may compensate for fatigue by prioritising speed or accuracy, evidence suggests prolonged sleep deprivation affects both [22,23]. Previous studies have reported diminished accuracy and prolonged reaction times in memory tasks a notable proportion of healthcare workers on night duty, supporting the findings [24-26]. Similarly Del Angel J et al., reported reduced accuracy and increased reaction times to visuospatial tasks after 5 days of sleep restriction [25]. Harrison Y and Horne JA in a review synthesises evidence of sleep deprivation impairing decision making reliant on attention and memory through slower processing and precision. Sleep deprivation alters the thalamocortical connectivity, reduces the activity of sleep spindles especially in the frontocentral regions impairing synaptic plasticity responsible for memory consolidation and executive processing [27].

The lower FAB Total Global scores among shift workers support the involvement of frontal lobe mediated deficits including conceptualisation, mental flexibility, and executive functions. Functional deterioration of prefrontal, premotor, ant cingulate and post parietal regions, areas which are important in planning, execution and motor control, have been reported in sleep deprived conditions [28-30]. The Go/No-Go tasks provided additional insight into inhibitory control and autonomic reactivity under cognitive load. Sleep debt increases the vulnerability of the prefrontal inhibitory circuits especially the dorsolateral and orbitofrontal areas. Response inhibition, a key frontal executive function enabling suppression of inappropriate actions is weakened by sleep loss due to impaired inhibitory gating [31]. Neurophysiologically, sleep deprivation alters the noradrenergic and dopamine modulation from prefrontal cortex, reducing signal to noise ratio and further impaired response inhibition [1].

During the Go no go task the heart rates of shift workers was (90.01±17.50) statistically higher as compared to the controls (82±15.66) indicating sympathetic activation to cognitive stress although systolic blood pressure differences were elevated in shift workers during the task they were not statistically significant in contrast to the diastolic blood pressure which was significantly elevated compared to their night rested counterparts. The present study has results similar to another study which has suggested a blunted BP dipping response in shift workers [32]. Neuroimaging studies have implicated the activation of pre cuneus, pre supplementary motor areas and right middle, inferior frontal gyrus for sympathetic activity and attentional processes, response inhibition tasks, anxiety and altered frontal functions, respectively [31,33]. The results of Go No Go test suggest a reduced reaction time for Stops among shift workers (71.81±11.04) compared to controls (80.66±12.01) suggesting a greater impulsivity among them. The omission rates were (19.8±9.91) among shift workers as compared to controls (14.24±12.09) suggesting errors in planning and execution in them. The Commission error rates to a No-Go trial among shift workers were higher (77.84±11.7) as compared to their counterparts (69.09±9.88). These findings suggest an impaired inhibitory control, an increased impulsivity, altered cognitive control and a reduced top-down regulation by the prefrontal cortex in sleep deprived. Nurses heavily rely on these abilities to effectively organise, anticipate potential problems, and when these skills are compromised, nurses may experience difficulties in providing optimal patient care, leading to adverse outcomes.

Limitation(s)

The sample size included in the present study may limit the generalisability for older nurses as well as it being limited to a single hospital setting. Further data from multiple settings can help build generalisability. Second the sleep duration and quality were assessed using self-reported questionnaire and not objectively using an actigraph.

CONCLUSION(S)

Present study concluded that shift work negatively impacts cognitive processes like impaired visuo-spatial ability, reduced attention (including focus and task switching) and slower motor programming compared to their controls highlighting the occupational challenge faced by nurses and underscoring the need for targeted interventions to safeguard their health. Implementation of evidence-based duty roster, adequate sleep periods and sleep optimisation strategies are recommended to mitigate the adverse cognitive and autonomic effects of night shift work among nurses.

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