


Original Article

Continuous wakefulness of short duration: Effects on psychomotor cognitive performance and subsequent sleep physiology

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ABSTRACT

Objectives: It is not an uncommon situation that aircrews are exposed to continuous wakefulness and prolonged duty periods. The present study intended to understand the effects of continuous wakefulness of varying hours on psychomotor cognitive functions and physiological attributes of sleep.

Material and Methods: In a repeated measure design, psychomotor cognitive functions were evaluated among 20 healthy aircrew during a period of forced wakefulness of 18 h by CogScreen aeromedical edition on three successive sessions; 1st (baseline) at 0800–0900 h, 2nd at 1900–2000 h and 3rd at 2300–0000 h. The sleep architecture and bio-physiological parameters were studied with Alice 5 Polysomnography System® in the subsequent sleep period following 18-h of continuous wakefulness.

Results: Consistent improvements in performance were observed in many tasks as a result of repetitive practice effects. The speed measures pertaining to computational math skills, reading comprehension and logical reasoning, sustained attention, and visual motor tracking were significantly affected in the 3rd session compared to the 2nd session. Similarly, there was a significant decrement in immediate and delayed visual paired associate memory in the 3rd session compared to 2nd session, whereas spatial processing and visual working memory showed a significant longitudinal decrement in accuracy scores across the period of wakefulness. The sleep architecture and the bio-physiological variables of sleep were found to be within the normal physiological limits.

Conclusion: Few aspects of higher cognitive functions were adversely affected during continuous wakefulness of 18 h, even though such a period was not found to affect sleep architecture and bio-physiological variables of sleep.

Keywords: Attention, Cognition, Memory, Polysomnography, Sleep, Wakefulness

INTRODUCTION

Sleep is a vital biological function of humans as it is essential to maintain waking performance and productive thinking. Without enough sleep, the ability to perform even simple tasks gets affected dramatically.^[1] Human beings exhibit a diurnal pattern of sleep and wakefulness over the course of a 24-h, in which alertness waxes and wanes throughout the day in a predictable manner.^[2] The effects of sleep loss resulting in degradation of neurocognitive performance have been well established.^[3,4] Similarly, the effects of desynchronization of circadian rhythms leading to daytime sleepiness and a decrement in sleep quality have also been well documented.^[5]

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Modern military and civil aviation are characterized by operations of extended wakefulness lasting for periods that exceed an individual's capability to maintain efficient performance. Though aviation operations can continue for extended periods, aircrews need periodic sleep for the restitution of physiological and cognitive functions. However, if the aircrew remains awake for extended periods, the possibility of performance decrement arising out of consequences of sleep deprivation and altered circadian rhythm is a likely eventuality. Even these conditions are known to affect sleep physiology and architecture in the subsequent periods.^[6,7]

During sustained and continuous operations of long duration, preventive measures with sleep-alertness management have been routine practices in many Air Forces worldwide.^[8] However, extended wakefulness of short duration is a more practical reality in both military and civil air operations. The relevance of performance deficits during such realistic periods of extended wakefulness to aerospace operations that require high-level cognitive performance is a desired exploration. With this background, the present study was conducted to understand the implications of continuous wakefulness of 18 h on psychomotor cognitive functions using aviation-specific neurocognitive test batteries and subsequent sleep physiology using an objective sleep assessment tool.

MATERIAL AND METHODS

Subjects

Twenty healthy aircrew volunteers between 20 and 35 years participated in the study. The exclusion criteria were the presence of any illness, sleep disorders, those on medications, and history of inadequate sleep the previous night.

Materials

CogScreen-Aeromedical Edition (CogScreen-AE) was used for the assessment of psychomotor cognitive functions. CogScreen-AE assesses the speed and accuracy measures pertaining to 11 subtests - backward digit span, symbol digit coding test, math test, visual sequence test, matching to sample test, manikin test, divided attention test, auditory sequence comparison test, pathfinder test, shifting attention test, and dual task. Alice 5 System[®] was used for recording of polysomnographic data on sleep architecture and bio-physiological variables of sleep.

Experimental protocol

The study was conducted in the controlled environment of a sleep lab. Three days before the day of the experiment, each subject was briefed to have adequate rest and follow their

routine sleep habits at night. They were advised not to involve themselves in heavy strenuous activities, consume alcohol, and attend social functions at night that may interfere with normal sleep patterns. The study participants reported to the sleep laboratory at 0745 h on the respective days of experiment. They were briefed completely on the test protocol and informed written consents were obtained. The subject's wake time was noted. Baseline psychomotor cognitive functions were tested at 0800–0900 h using CogScreen-AE (1st Session - S1). The participants were then subjected to forced wakefulness of 18 h. Psychomotor cognitive functions were again tested at 1900–2000 h (2nd Session - S2) and repeated at 2300–0000 h (3rd Session - S3). Following S3, the leads of Alice 5 Polysomnography System[®] were attached to the participants and they were advised to sleep in the sleep laboratory. The sleep architecture and bio-physiological parameters of sleep (heart rate and oxygen saturation [SpO₂]) were then studied in the controlled environment of the sleep laboratory.

Statistical analysis

Results on continuous measurements were presented on mean \pm standard deviation (Min-Max) and on categorical measurements were presented in number. Repeated measure analysis of variance was used to analyze the speed measures (reaction time) and accuracy measures (%) across the various subtests of CogScreen-AE. Student's- *t*-test was used to find the difference in physiological parameters (heart rate and SpO₂) between non-rapid eye movement (NREM) and rapid eye movement (REM) sleep. Significance was set at $P < 0.05$ level.

RESULTS

The data were found to be normally distributed. The analysis of the 11 CogScreen subtests pertaining to speed measures and accuracy scores across the three sessions is shown in Tables 1 and 2, respectively.

The polysomnographic findings of sleep pattern and sleep architecture of the participants are presented in Tables 3 and 4, respectively. The analysis of physiological parameters (heart rate and SpO₂) as revealed from polysomnography is given in Table 5.

DISCUSSION

The present study intended to examine the changes in psychomotor cognitive performance among 20 aircrew subjects during periods of extended wakefulness of 18 h, a practical eventuality during both in military and civil aviation. Psychomotor cognitive functions were assessed in the controlled laboratory conditions using CogScreen-AE. The tool includes measures of cognitive functions considered

Table 1: Speed measures (reaction times in seconds) CogScreen-AE.

Task	Baseline (S1) Mean±SD	Continuous wakefulness of 13–14 h (S2)	Continuous wakefulness of 17–18 h (S3)	Repeated measure ANOVA		Pairwise comparison between the sessions (P-value)		
				F	P-value	S1-S2	S2-S3	S1-S3
Math	27.82±8.96	23.42±6.59	26.54±6.28	4.871	0.013	0.006	0.015	0.465
Visual sequence comparison	2.18±0.62	1.91±0.46	1.95±0.47	4.257	0.021	0.007	0.607	0.091
Matching to sample	1.36±0.39	1.27±0.3	1.30±0.39	2.323	0.112	0.06	0.554	0.134
Manikin	1.60±0.31	1.49±0.29	1.47±0.33	1.913	0.162	0.138	0.908	0.120
Divided attention	1.03±0.30	0.95±0.24	0.96±0.26	10.126	0.001	0.002	0.238	0.003
Auditory sequence comparison	0.70±0.17	0.68±0.12	0.65±0.13	0.656	0.525	0.696	0.331	0.348
Pathfinder	1.02±0.34	0.88±0.14	0.83±0.13	5.866	0.006	0.028	0.136	0.020
Shifting Attention	0.80±0.12	0.72±0.13	0.70±0.10	6.363	0.004	0.057	0.340	0.001
Dual task	0.64±0.21	0.52±0.16	0.58±0.20	5.894	0.006	0.005	0.013	0.185

CogScreen-AE: CogScreen-Aeromedical Edition, ANOVA: Analysis of variance, Bold values denote significance

Table 2: Accuracy measures (percentage) CogScreen-AE.

Task	Baseline (S1) Mean±SD	Continuous wakefulness of 13–14 h (S2)	Continuous wakefulness of 17–18 h (S3)	Repeated measure ANOVA		Pairwise comparison between the sessions (P-value)		
				F	P-value	S1-S2	S2-S3	S1-S3
Math	79±18.9	85±17	75±24.1	2.051	0.143	0.186	0.086	0.428
Visual sequence comparison	98.7±2.7	98.2±3.7	98±3.4	0.357	0.702	0.606	0.804	0.330
Backward digit span	84.5±14.2	87.3±17.8	87.5±13.4	0.707	0.499	0.393	0.936	0.260
Symbol digit coding task	94.3±7.2	90±13.8	86±12.2	3.237	0.05	0.211	0.007	0.290
Matching to sample	94±6.1	91.5±6.1	88±7.8	10.579	<0.001	0.048	0.022	<0.001
Manikin	92.5±11.7	90.8±11.4	94.6±8.6	1.234	0.303	0.577	0.205	0.143
Divided attention	91.6±7.4	93.5±3.9	93.5±4.0	0.766	0.472	0.357	0.995	0.336
Auditory sequence comparison	90.5±8.2	90±10.7	93±8.6	0.967	0.389	0.858	0.230	0.135
Pathfinder	98.8±1.3	97.9±5.1	99±1.44	0.200	0.819	0.802	0.748	0.432
Shifting attention	84.6±6.7	88.3±5.6	89.7±3.7	6.218	0.005	0.039	0.260	0.005
Dual task	88.8±6.7	90.5±7.5	90.8±6.1	1.102	0.343	0.123	0.871	0.161

CogScreen-AE: CogScreen-Aeromedical Edition, ANOVA: Analysis of variance, Bold values denote significance

Table 3: Polysomnography - Sleep patterns (n=20).

Sleep pattern	Mean±SD
Sleep period time (h)	5.64±0.66
Total sleep time (h)	5.41±0.66
Sleep latency (min)	8.9±5.51
REM (R) latency (min)	83±26.45
Wake during sleep (min)	13.67±8.28
Slow-wave sleep (min)	59.2±18.11
Sleep efficiency	95.88±2.36

SD: Standard deviation, REM: Rapid eye movement

essential to skilled aviation performance and has been found to be predictive of flight performance.^[9] The time periods of administering CogScreen tests in the study were specifically

chosen taking into consideration the usual timings for night flying.

Consistent improvements in performance were observed specially in speed measures [Table 5] in many CogScreen-AE tasks as a result of repetitive practice and learning outcome. Even though each of the CogScreen-AE subtests is preceded by practice sessions, a significant improvement in the task performance in similar tasks has been well documented in the literature due to repeated administration of task and learning effects thereof.^[10-12] Studies on similar tasks have shown that asymptotic level of performance is generally seen after two repetitions even on separate occasions.^[13]

Analysis of individual subtests of CogScreen-AE revealed some important observations during periods of continuous wakefulness. Math task which measures computational math

Table 4: Polysomnography - Sleep architecture (n=20).

Sleep stages	Mean±SD	
	Duration (min)	% of total sleep time
Non rapid eye movement stage		
Stage I (N1)	27.05±9.23	8.1±3.5
Stage 2 (N2)	172.75±29.72	50.8±8.6
Stage 3 (N3)	59.2±18.11	19.5±6.1
Rapid eye movement stage (R)	65.75±17.26	20.1±4.72

SD: Standard deviation

skills, attention, concentration, working memory, reading comprehension, and logical reasoning, showed a consistent significant increase in response speed across the periods of continuous wakefulness. In the symbol digit coding task, the accuracy scores were significantly reduced between 1st and 3rd sessions in spite of the expected practice outcome. This finding is considered significant as this task among all the CogScreen-AE subtests is designed to measure immediate and delayed visual paired associate memory.^[9] In the matching to sample task, the accuracy scores showed consistent significant reduction across the three sessions. Hence, the accuracy on the mental abilities such as spatial processing and visual-working memory as measured by this task could be adversely affected by periods of extended wakefulness, even of short duration.

In the divided attention and dual tasks, which are the measures of divided attention, there was no change in accuracy scores across the three sessions [Table 1]. However, analysis of response time [Table 5] revealed differential sensitivity of the two divided attention tasks to the effects of prolonged wakefulness. The response time was significantly decreased in both the tasks in 2nd and 3rd sessions as compared to baseline values, an expected outcome as a result of practice and learning effect. However, the speed performance was significantly affected between 2nd and 3rd sessions in dual task, whereas, there was no significant variation in the measure in divided attention task. Dual task involves performance of a visual tracking task and a visual memory task. By contrast, in divided attention task, subjects have to perform visual attention task and visual-verbal memory task. Thus, divided attention task places demands separately on visual and verbal modalities; and therefore, it has less of an executive component. Whereas, dual task loading heavily on visual processing, has greater executive demands. As observed in the present study, prolonged wakefulness had a significantly greater impact on dual task indicating its effects on executive functions. Differential sensitivity to these tasks has also been observed in the previous studies involving CogScreen.^[11]

In addition to psychomotor cognitive functions, present study examined the effects of continuous wakefulness on sleep

Table 5: Polysomnography - Physiological parameters (n=20).

Sleep stages	Mean±SD	
	Heart rate (bpm)	SpO ₂ (%)
Wake	71.69±10.36	97.85±0.98
NREM	63.11±9.53	97.2±0.76
REM	65.62±10.1	97.6±0.82
P-value		
Between wake – NREM	<0.001	<0.001
Between NREM – REM	<0.001	<0.001

SD: Standard deviation, NREM: Non-rapid eye movement, REM: Rapid eye movement

architecture and bio-physiological parameters of sleep in the subsequent sleep period. In the present study [Tables 2 and 3], the mean duration of NREM sleep was 259 ± 28.9 min in contrast to REM duration of 65.7 ± 17.2 min. The mean duration of N1, N2, and N3 was 27 ± 9.2, 172.7 ± 29.7, and 59.2 ± 18.11 min, respectively. Thus, the absolute duration of each of the stages was reduced as the total duration of sleep was less. In terms of the percentage of total sleep duration, the stages N1, N2, N3, and REM constituted 8.1 ± 3.5%, 50.8 ± 8.6%, 19.5 ± 6.1%, and 20.1 ± 4.7%, respectively, which were within the normal physiological limits.^[14] Results from this study thus indicate that when total sleep time is shortened, the percentages of sleep in each stages get truncated as shown in previous study.^[15] “Sleep efficiency,” expressed as a percentage, indicates effective sleep achieved in a sleep episode.^[16] The sleep efficiency is measured by total sleep time/total sleep period. Sleep efficiency >80% is considered normal. In the present study, mean sleep efficiency was 94.88%. The efficiency of sleep is also measured by the quantity of slow-wave sleep and REM which normally amounts to 25–40% of total sleep duration. This was observed to be 40.24 ± 8.92% in our study. Thus, sleep efficiency was considered to be satisfactory. Analysis of the physiological parameters [Table 4] revealed the mean heart rate and SpO₂ during the wake period to be 71.69 ± 10.36 bpm and 97.75 ± 0.91%, respectively. The mean heart rate was reduced to 63.11 ± 9.53 bpm in the NREM stage and this reduction was statistically significant ($P < 0.001$). Compared to NREM stage, the mean heart rate was increased to 65.62 ± 10.1 bpm in the REM stage and this rise was also statistically significant ($P < 0.001$). Similarly, the mean SpO₂ significantly dropped to 97.2 ± 0.76% in the NREM stage, which again showed a significant rise in the REM stage to 97.85 ± 0.98%. The observed changes in the heart rate and SpO₂ thus showed a normal physiological response of sleep.^[17]

The study had few limitations. First, the effects of learning due to test repetition could not be overcome even though each CogScreen AE sub-tests battery is preceded by practice session. The learning effect could have been avoided

by employing repeated test sessions before employing experimental testing. Second, the effects of circadian rhythm on cognitive performance could not be eliminated within the present study design, even though such an effect was not expected in the time period when testing was carried out.

CONCLUSION

Few aspects of higher cognitive functions were adversely affected during continuous wakefulness of 18 h. This could be concluded from the following observations; (a) consistent improvements in performance were observed specially in speed measures in many CogScreen-AE tasks as a result of repetitive practice and learning outcome. (b) The accuracy measures pertaining to spatial processing and visual-working memory as measured by matching to sample task showed a significant longitudinal decrement across the periods of continuous wakefulness and (c) a differential sensitivity to continuous wakefulness was observed on the speed measures between the two divided attention tasks. Higher executive functions including visual motor tracking, as assessed by dual task, could be affected in the later part of extended wakefulness. However, such a period of extended wakefulness was not found to affect sleep architecture and bio-physiological variables of sleep.

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