A Pilot Study Exploring the Effects of Sleep Deprivation on Analogue Measures of Pilot Competencies

Anna Donnla O'Hagan; Johann Issartel; Eoghan McGinley; Giles Warrington

INTRODUCTION: Sleep loss can result in cognitive, motor, and neurobehavioral impairments. In an aviation context, this can cause a serious threat to flight safety. Therefore, the study aimed to investigate the effects of 24-h sleep deprivation on mood, fatigue, and airline pilot competencies.

METHODS: Seven subjects attended two 24-h testing periods, one with an 8-h sleep opportunity, and the other with no sleep opportunity (i.e., sleep deprivation). Subjects were required to complete a battery of mood, fatigue, and analogue measures of pilot competency tasks every 8 h (0 h, 8 h, 16 h, 24 h) throughout each testing period.

RESULTS: While total mood disturbance was found to significantly increase (83.42, SD = 25.7), both objective (352.71, SD = 42.00) and subjective (34.85, SD = 8.82) fatigue were found to significantly decrease following 24-h sleep deprivation. Cognitive flexibility (757.45, SD = 58.48) and hand-eye coordination (dominant hand only) (60.28, SD = 3.86) were also negatively impacted following 24-h sleep deprivation. However, working memory and situation awareness were not significantly negatively impacted by the bout of sleep deprivation.

DISCUSSION: Some pilot-specific task-related factors such as subjective fatigue, cognitive flexibility, and working memory were found to be particularly susceptible to sleep loss, with significant declines in performance observed following 16-h continuous wakefulness, suggesting reductions in optimal functioning following this period of wakefulness. Further investigation using more regular testing time points, employing additional pilot competencies, and using more aviation-specific tasks is warranted.

KEYWORDS: fatigue, aviation, pilot performance, cognitive function, flight safety.

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Sleep is a fundamental component of human life. Although a full understanding of the functions and purpose of sleep remain unknown, it is clear that it plays a vital role in the restoration of physical and mental functioning. Furthermore, it has been well established that sleep loss and sleep deprivation can result in significant cognitive, motor, and neurobehavioral impairments.[18] According to the research, sleep deprivation is associated with a decline in attention and vigilance, greater negative mood disturbances, slower reaction times, reductions in decision-making, and a decline in working memory.[5,16] Several reviews and meta-analyses have been published summarizing these research findings.[2,8] However, existing research investigating the effects of sleep deprivation on occupation-specific competencies within certain working industries, such as the aviation domain, are sparse, meriting further research in this area.

While previous sleep research has been conducted within the field of aviation and performance,[5,12] studies investigating the impact on pilot skills and performance have been somewhat limited. Some studies have investigated the impact of sleep deprivation on occupation-specific skills in certain professions such as doctors,[10] commercial drivers,[4] and military personnel.[14] According to research conducted by Grantcharov and Bardram,[11] surgeons-in-training who experienced sleep deprivation took significantly more time to complete a virtual laparoscopic surgery, made significantly more errors, and had significantly more unnecessary movements during the surgery

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tasks. Additionally, in a study conducted by Bloomfield, Harder, and Chihak,[4] following 20 h of sleep deprivation, commercial vehicle drivers' steering performance was impaired while both steering instability and driving speed significantly increased. In contrast, a full scientific understanding of the impact of sleep deprivation on commercial airline pilot competencies still remains unknown. Any industry which operates 24-h activities is highly susceptible to human error as a result of sleep deprivation; therefore, it is important to be aware of the influence of sleep loss on those workers' occupation-specific competencies.

According to the International Civil Aviation Organization's (ICAO) manual of evidence-based training, which is intended to provide guidance to the Civil Aviation Authorities (CAA), operators, and approved training organizations, there are eight core pilot competencies. These core competencies are defined as a group of related behaviors, based on job requirements, which describe how to effectively and proficiently perform a job.[11] They are: Application of Procedures, Communication, Problem Solving and Decision-Making, Situation Awareness, Aircraft Flight Path Management—Automation, Aircraft Flight Path Management—Manual Control, Leadership and Teamwork, and Workload Management. A detailed description and behavioral indicator of each competency is included in the 2013 ICAO Manual of Evidence-Based Practice.

According to the ICAO manual,[11] problem solving and decision-making are described as the ability to accurately identify risks and resolve problems as well as use appropriate decision-making processes. Pilots are often required to innovatively respond to unique problems, novel task demands, and make timely and correct decisions in chaotic situations.[1] Therefore, pilots must be able to successfully traverse from thinking about one concept (e.g., calculating how long they can remain in the hold for diversion to a new alternate) to another (e.g., intercepting the localizer), a multitasking skill which relies heavily on their cognitive flexibility. Furthermore, according to the problem solving and decision-making behavioral descriptor, pilots must also be able to monitor, review, and adapt decisions as required, all while working through problems without reducing safety. Pilots are required to sense, organize, and use information resulting in the use of resources from both their short-term and long-term memory systems.[1] This requires pilots to have an excellent functioning working memory. As well as being able to solve complex problems in high pressure and demanding situations, pilots must also be able to maintain excellent awareness of themselves and the environment around them. Situation awareness is the ability to perceive and comprehend all relevant information available and anticipate what could happen that may affect the operation.[11] It is considered a basic requirement of good airmanship and forms the basis for pilot decision-making and performance.[9]

In addition to spatial awareness, hand-eye coordination is an additional competency which is vital for airline pilots to allow for successful operation and navigation of the aircraft. In order to successfully operate an aircraft, a pilot requires high levels of perceptive, cognitive, and motor ability to ensure appropriate reaction to changing environments and situations. Precision of movement is vital to ensure the successful execution of fine motor skills, for which such skills are required for numerous actions associated with the trim control or switches.[13]

Air travel is growing in popularity year by year, resulting in today's flight operations and pilots working pressurized 24/7 timetables. The unrelenting escalation in international long-haul, short-haul, regional, and overnight operations will continue to increase these round-the-clock requirements, which pose a potential threat for human error over time as a result of sleep deprivation. As such, it is important to question to what extent and at what point in time are pilots' competencies impaired by sleep loss. The ecological validity of this question is highlighted by sleep/fatigue-related aviation disasters, including the 1997 Korean Air flight 801 crash in which 228 people died, the 1999 the American Airlines flight 1420 accident which claimed 11 lives, and the 2004 Corporate Airlines Flight 5966 crashing on its approach to Kirksville Regional Airport, killing 11 of its 13 passengers and 2 crew.

The potential risks of sleep loss and sleep deprivation have previously been somewhat disregarded by society despite evidence highlighting the increased threats to health and safety. As a result, greater information pertaining to the full implications and subsequent consequences of the effect of sleep deprivation and fatigue on performance is required. The aim of this study was, therefore, to investigate the effect of 24-h sleep deprivation on mood, fatigue, and airline pilot competencies, specifically cognitive flexibility and working memory (indicators of the problem solving and decision-making core competency), situation awareness, and motor and hand-eye coordination. Determining the effects of sleep deprivation on airline pilot competencies will aid in its effective management, thus reducing risk and enhancing safety.

The present study contained several key limitations which should be noted now. Firstly, due to the pilot nature of this research, seven university levels students, as opposed to commercial airline pilots, were recruited to take part in this research. Secondly, this study employed analogue, as opposed to direct, measures of airline pilot core competencies, some of which were subjective and not aviation-specific in nature. While these factors act as potential limiters of this research, it did measure cognitive skills which are required and used during real-world flying tasks.

METHODS

Subjects

A convenience sample comprised of seven male university level subjects (age 21 ± 1 yr, height 182.01 ± 7.71 cm, weight 83.27 ± 9.64 kg), who are part of the School of Health & Human Performance and were not qualified pilots, were recruited to participate in this study. All subjects were nonsmokers, not presently taking any form of medication and refrained from alcohol and heavy exercise for the 24 h prior to each testing protocol. None had previously engaged in sleep deprivation studies or reported sleep disorders as determined by the SLEEP-50 questionnaire. They also maintained normal sleeping and eating habits for the 72 h prior to each testing protocol. Subjects were not permitted to ingest any caffeine and were provided with all meals by the researchers during each testing session. Prior to any data collection, ethical approval was granted by Dublin City University Ethical Committee. All subjects provided written consent prior to participation.

Measures

Table I contains an overview of the variables under investigation, the associated indicator, and the analogue measures employed in the present study. Mood state was assessed using the Profile of Mood States Questionnaire (POMS). POMS is a 65-item scale which has been proven to be valid among healthy adult populations and has a high internal consistency. A seventh score of Total Mood Disturbance (TMD) was also calculated with this measure.

Subjective fatigue was measured using the Fatigue Severity Scale (FSS). The FSS has been found to be a simple yet reliable instrument for measuring subjective fatigue and has also been shown to have high internal consistency and good test-retest reliability.

Objective fatigue was determined using the Psychomotor Vigilance Task (PVT). This 10-min visual psychomotor task was conducted on the PC-PVT ver. 1.1.0, which has been shown to compare favorably to the gold standard PVT-192 device. Mean reaction time (MRT) was recorded along with lapses in attention (a response time of $>$500 ms).

Cognitive flexibility was determined by the Stroop Color and Word Test (SCWT) measured using Inquisit 4 Web (Computer software, 2015; Millisecond Software, Seattle, WA; https://www.millisecond.com/). The Stroop Test has been found to be reliable and one of the best and most used measures of inhibitory processes and cognitive flexibility.

Working memory was determined using the Auditory Digit Span (Forward & Backward) Test (ADS) of the Wechsler Adult Intelligence Scale—Fourth Edition. This test is one of the oldest and most widely used neuropsychological test of working memory. The raw score for the maximum number of digits recalled was used as the outcome measure in both the forward and backward trials.

Situation awareness was assessed using the Situation Awareness Rating Technique (SART), which was completed following performance of a computerized flight simulator task on a YSFlight Simulator (ver. 20,130,805). This is a simplistic post-trial subjective rating measure which was originally developed to assess pilots' situational awareness. Subjects were required to land an aircraft using a preset scenario, following which they were required to complete the SART.

Hand-eye coordination was determined using the Grooved Pegboard (GPB) test (Model 32,025, Lafayette Instruments, Lafayette, IN). This is a test of hand-eye coordination and motor speed which requires sensory motor integration and a high level of motor processing.

Table I. Overview of the Variables, Competencies, Indicators, and Measures Used.

VARIABLES	MEASURES
Mood	
Subjective Mood	Profile of Mood States
Fatigue	
Subjective Fatigue	Fatigue Severity Scale
Objective Fatigue	Psychomotor Vigilance Task
Airline Pilot Competencies	
Cognitive Flexibility	Stroop Color & Word Test
Working Memory	Auditory Digit Span Test
Situation Awareness	Situation Awareness Rating Technique
Hand-Eye Coordination	Grooved Pegboard

Procedure

This study employed a repeated measures crossover design with subjects acting as their own controls. Habituation testing was followed by two 24-h testing periods [one with an 8-h sleep opportunity and the other with no sleep opportunity (i.e., sleep deprivation)]. Each testing period was separated by a minimum of 7 d to allow for sufficient rest and recuperation.[16] Subjects were randomly assigned to their order of testing and were familiarized with the experimental tests and procedures during their initial visit to the laboratory. In all instances, familiarization testing took place 4 d prior to the first data collection period. Due to availability of facilities and equipment, data collection for individual subjects commenced at 60-min intervals beginning at 0700 or 0800. Sleep and waking schedules were manipulated to ensure all subjects were tested at the same points post-waking throughout each testing period. The testing protocol and procedure was identical during both the 'sleep' and 'no sleep' testing periods. Subjects were instructed to wake 30 min prior to their scheduled start time after approximately 8 h sleep, and report to the laboratory immediately.

Each testing period consisted of four identical testing sessions which were performed every 8 h (0 h, 8 h, 16 h, 24 h). The duration of each testing session lasted for 60 min and consisted of a battery of mood (Subjective Mood), fatigue (Subjective Fatigue and Objective Fatigue), and analogue measures of airline pilot competencies [specifically Cognitive Flexibility and Working Memory (indicators of the Problem Solving and Decision-Making core competency), Situation Awareness, and Hand-Eye Coordination].

During free time, subjects engaged in sedentary activities, including reading, watching TV, and playing cards. The investigators maintained constant vigilance over subjects and, if dozing was identified, subjects were gently but quickly awoken. Subjects remained in the laboratory for the full duration of both testing periods with full sleeping facilities provided during the 'sleep' condition.

Statistical Analysis

All statistical analysis was performed using SPSS Version 23 (IBM, Armonk, NY). A 2 $\times$ 4 repeated measures ANOVA within-subject design was carried out to determine whether there was a significant difference between all tests (mood, fatigue, and airline pilot competencies) at the different time points (0 h, 8 h, 16 h, 24 h). Post hoc analysis using a Bonferroni test was used to identify where these differences lie. In instances where Mauchly's test of sphericity was significant, the Greenhouse-Geisser adjusted degrees of freedom were used. An alpha value of $P < 0.05$ was used to determine statistical significance.

RESULTS

Table II provides the results for the 2 × 4 repeated measures ANOVA for each of the dependent variables. An interaction effect was found for both fatigue [$F(3,18) = 7.895$, $P = 0.001$] and TMD [$F(3,18) = 3.887$, $P = 0.026$], as determined by the POMS. At the 24-h time point, the 'no sleep' condition reported significantly higher levels of fatigue [$t(6) = -4.885$, $P = 0.003$ (see **Fig. 1**)] and significantly greater levels of mood disturbance [$t(6) = -4.488$, $P = 0.004$] in comparison to the 'sleep' condition. As regards the fatigue subscale, significantly greater levels of fatigue were reported at the 24-h time point in comparison to the 0-h [$F(3,18) = 19.819$, $P = 0.009$], 8-h [$F(3,18) = 19.819$, $P = 0.013$], and 16-h [$F(3,18) = 19.819$, $P = 0.016$] time points in the 'no sleep' condition. Furthermore, TMD increased with increasing time awake with significantly greater TMD reported at the 24-h time point in comparison to the 0-h [$F(3,18) = 15.482$, $P = 0.014$] and 16-h time points [$F(3,18) = 15.482$, $P = 0.019$] in the 'no sleep' condition. A significant condition main effect was found for depression [$F(1,6) = 8.681$, $P = 0.026$], with significantly greater levels of depression reported at the 24-h point between the 'sleep' and 'no sleep' conditions [$t(6) = -3.012$, $P = 0.024$].

Subjective fatigue revealed an interaction effect [$F(3,18) = 3.025$, $P = 0.05$]. Post hoc comparisons showed significantly higher fatigue scores between the 'sleep' and 'no sleep' conditions at the 24-h time point [$t(6) = -4.074$, $P = 0.007$]. Furthermore, subjective fatigue scores were significantly higher at the 24-h time point relative to the 0-h time point [$F(3,18) = 4.132$, $P = 0.026$] in the 'no sleep' condition.

An interaction effect was found for both 'lapse in attention' (response time of >500 ms) [$F(3,18) = 8.599$, $P = 0.001$] and Mean Reaction Time [$F(3,18) = 7.511$, $P = 0.002$ (see **Fig. 2**)]. At the 24-h time point, the 'no sleep' condition reported significantly more lapses in attention [$t(6) = -3.029$, $P = 0.023$] and significantly slower reaction times [$t(6) = -2.627$, $P = 0.039$] in comparison to the 'sleep' condition. Additionally, significantly more lapses in attention were reported at the 24-h time point in comparison to the 0-h [$F(1.083,18) = 13.001$, $P = 0.049$] and 16-h [$F(1.083,18) = 13.001$, $P = 0.039$] time points in the 'no sleep' condition. As regards mean reaction time, significantly slower reaction times were reported at the 24-h time point in comparison to the 16-h time point [$F(3,18) = 10.299$, $P = 0.030$] in the 'no sleep' condition.

The analysis of the Stroop Test reveals a significant interaction effect for the incongruent trials [$F(3,18) = 6.475$, $P = 0.004$]. As can be seen in **Fig. 3**, response times in the incongruent trials were significantly slower at the 16-h time point [$t(6) = -3.061$, $P = 0.022$] and the 24-h time point [$t(6) = -3.169$, $P = 0.019$] in the 'no sleep' condition vs. the 'sleep' condition. Furthermore, in the incongruent trials, significantly faster

Table II. Results of Analysis of Variance for the Two Conditions ('Sleep', 'No Sleep') at Four Time Points (0 h, 8 h, 16 h, 24 h).

DEPENDENT VARIABLE	TIME MAIN EFFECT	CONDITION MAIN EFFECT	INTERACTION EFFECT
Mood			
Tension	$F = 0.541$; $P = 0.661$	$F = 3.891$; $P = 0.096$	$F = 0.697$; $P = 0.566$
Depression	$F = 2.384$; $P = 0.103$	$F = 8.681$; $P = 0.026$*	$F = 2.941$; $P = 0.061$
Anger	$F = 2.501$; $P = 0.143$	$F = 1.156$; $P = 0.324$	$F = 2.619$; $P = 0.082$
Fatigue	$F = 15.767$; $P = <0.001$***	$F = 7.490$; $P = 0.034$*	$F = 7.895$; $P = 0.001$***
Vigor	$F = 14.470$; $P = <0.001$***	$F = 1.682$; $P = 0.242$	$F = 2.330$; $P = 0.109$
Confusion	$F = 8.686$; $P = 0.001$***	$F = 2.576$; $P = 0.160$	$F = 1.848$; $P = 0.175$
Total Mood Disturbance	$F = 19.232$; $P = <0.001$***	$F = 8.615$; $P = 0.026$*	$F = 3.887$; $P = 0.026$*†
Subjective Fatigue			
FSS	$F = 3.729$; $P = 0.030$*	$F = 2.754$; $P = 0.148$	$F = 3.025$; $P = 0.057$*
Objective Fatigue			
PVT: Lapses in Attention	$F = 13.516$; $P = 0.006$**†	$F = 6.198$; $P = 0.047$*	$F = 8.599$; $P = 0.017$**
PVT: Mean Reaction Time	$F = 8.214$; $P = 0.001$***	$F = 2.284$; $P = 0.181$	$F = 7.511$; $P = 0.002$**
Problem Solving & Decision-Making: Cognitive Flexibility			
Stroop Test: Control	$F = 6.664$; $P = 0.003$**	$F = 0.990$; $P = 0.358$	$F = 1.666$; $P = 0.210$
Stroop Test: Congruent	$F = 4.044$; $P = 0.070$	$F = 0.076$; $P = 0.792$	$F = 0.517$; $P = 0.562$
Stroop Test: Incongruent	$F = 9.653$; $P = 0.001$***	$F = 3.097$; $P = 0.129$	$F = 6.475$; $P = 0.004$**
Problem Solving & Decision-Making: Working Memory			
Auditory Digit Span Forward	$F = 0.533$; $P = 0.665$	$F = 0.287$; $P = 0.611$	$F = 1.795$; $P = 0.224$†
Auditory Digit Span Backward	$F = 0.503$; $P = 0.685$	$F = 0.079$; $P = 0.788$	$F = 0.300$; $P = 0.825$
Situation Awareness			
Overall Situation Awareness	$F = 0.357$; $P = 0.785$	$F = 0.552$; $P = 0.485$	$F = 1.134$; $P = 0.362$
Hand-Eye Coordination			
GPB: Dominant Hand	$F = 1.074$; $P = 0.385$	$F = 0.069$; $P = 0.802$	$F = 6.765$; $P = 0.003$**
GPB: Non-Dominant Hand	$F = 0.972$; $P = 0.428$	$F = 0.176$; $P = 0.689$	$F = 0.489$; $P = 0.694$

* Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; †Greenhouse-Geisser adjusted degrees of freedom.

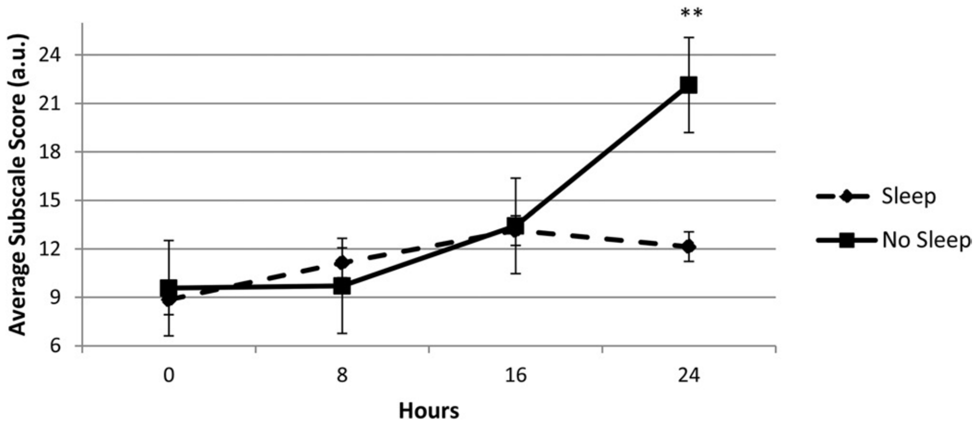

Fig. 1. Average fatigue subscale scores (± SE) for the 'Sleep' and 'No Sleep' conditions. $^{**}P < 0.01$.

response times were recorded at the 8-h time point [$F(3,18) = 10.578$, $P = 0.012$] and the 16-h time point [$F(3,18) = 10.578$, $P = 0.038$] in comparison to the 24-h time point in the 'no sleep' condition.

No significant interaction effect, condition main effect, or time main effect was found for the ADS Forward, the ADS Backward, or for situational awareness in the computerized flight task. With regard to the GPB, an interaction effect was found for the dominant hand only [$F(3,18) = 6.765$, $P = 0.003$]. At the 24-h time point, the 'sleep' condition recorded significantly faster times in comparison to the 'no sleep' condition [$t(6) = -2.948$, $P = 0.026$ (see **Fig. 4**)]. No significant differences across the time points were identified, although trends indicated that subjects got slower following the period of sleep deprivation.

DISCUSSION

The purpose of this study was to investigate the effects of a period of sleep deprivation on mood, fatigue, and airline pilot competencies, specifically cognitive flexibility and working memory (indicators of the problem solving and decision-making core competency), situation awareness, and hand-eye coordination among a group of university level students who were not qualified pilots. The main findings concluded that self-reported mood and both subjective and objective fatigue were significantly negatively impacted by 24-h sleep deprivation. As regards pilot competencies, analogue measures of these skills found that cognitive flexibility and hand-eye coordination (dominant hand only) significantly declined with increasing time awake. However, both working memory and situation awareness were not found to be significantly negatively impacted by the period of sleep deprivation.

Both fatigue and TMD significantly increased with increasing time awake. These results are in line with previous findings.[8,15] Current research suggests that there is an association between increased negative moods and sleep deprivation regardless of whether sleep deprivation is chronic or acute in nature. Furthermore, self-reported depression was significantly increased following 24-h sleep deprivation. It has been suggested that the interacting effects of depression could moderate additional mood states and performance. Preliminary research suggests that a depressed mood could decrease vigor and negatively influence all the other mood state variables.[16]

Subjective fatigue was also found to significantly increase with increasing time awake, with significant increases in subjective fatigue identified following 24-h sleep deprivation. It is widely agreed that sleep deprivation increases feelings of fatigue and insufficient sleep is considered one of the key factors which contribute to tiredness and sleepiness.[15] Objective fatigue findings appeared to very closely coincide with subjective findings. Both lapses in attention and mean reaction time on the PVT were significantly increased following 24-h sleep deprivation. According to Doran and colleagues[7] 'state instability' hypothesis, as loss of sleep continues, performance variability increases in a way which is reflective of the interaction of the homeostatic drive for sleep and the internal circadian drive for wakefulness, and the compensatory effort displayed by subjects to maintain performance. This hypothesis posits that following a substantial period of sleep loss, normal responses are not sustainable over time, despite compensatory effort, due to sleep initiation processes' chronic intrusion into wakefulness.

Subjects' ability to successfully switch from one response set to another (i.e., their cognitive flexibility) was found to decline with

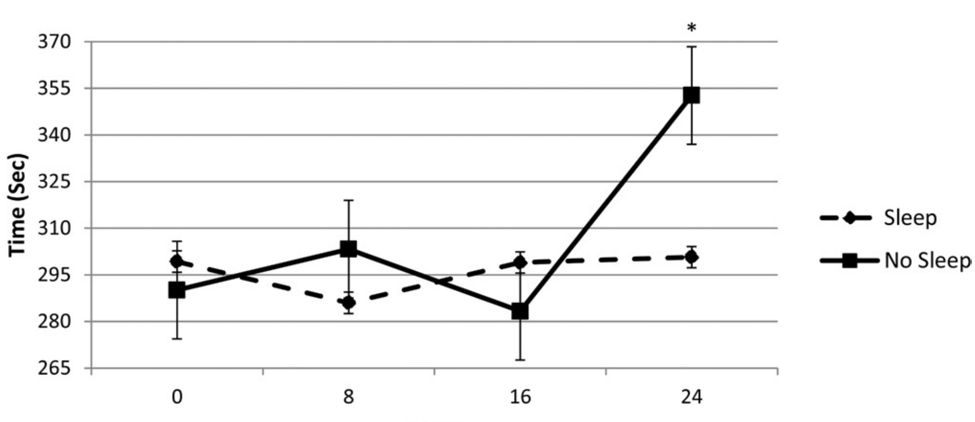

Fig. 2. Objective fatigue/mean reaction time (± SE) for the 'Sleep' and 'No Sleep' conditions. $^{*}P < 0.05$.

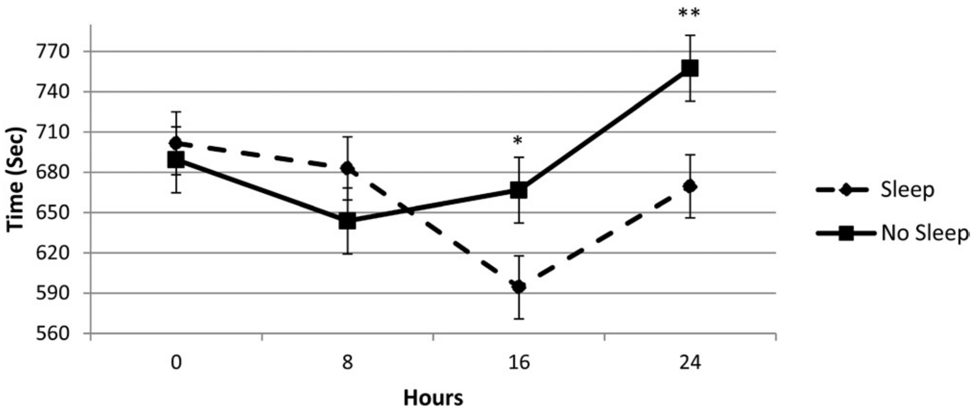

Fig. 3. Problem solving and decision-making—the Stroop Test: incongruent trial (± SE) for the 'Sleep' and 'No Sleep' conditions. $*P < 0.05$; $**P < 0.01$.

increasing time awake, with slower response times recorded following 24-h continuous wakefulness. Stimulating and short-duration executive tasks which involve the prefrontal cortex, such as planning, decision-making, and divergent thinking (i.e., skills which are dependent on spontaneity, creativity, and flexibility) are proposed to be sensitive to total sleep deprivation. However, not all results are in accordance with the proposed impact of sleep deprivation on executive functions, notably that of Binks and colleagues,[3] who did not find an effect for short-term sleep deprivation on a Stroop task. In the present study, cognitive flexibility was one of the first measures to be significantly negatively affected by sleep deprivation. Further investigation is needed to determine its potential as a precursor of sleep disturbance or sleep loss.

With regards to working memory, no significant declines in performance were found following the period of sleep deprivation. According to Waters and Bucks,[18] findings have been mixed regarding the effects of sleep deprivation on auditory, visual, and spatial short-term memory tasks. Some studies have found impaired digit recall performance following 24-h sleep deprivation, while others have not. While behavioral findings tend to display mixed results, neuroimaging studies have presented clearer findings.[6] Chee and Chuah[6] found a quantifiable effect on neural functions associated with a visual short-term memory task following 24-h sleep deprivation. The general decline in short-term memory following the period of sleep deprivation was associated with a reduction in intraparietal sulcus activity, which was in turn associated with a reduction in memory capacity. On the whole, it appears loss of sleep has a biological influence on short-term memory capacity which is not always detected via cognitive measures. As this present study did not employ neuroimaging techniques, it cannot conclude if this occurred in this instance.

In 'real-world' scenarios, the most serious consequences of sleep deprivation result from substantial cognitive or attentional failures. These substantial cognitive or attentional failures are often referred to as a loss of situational awareness, which is proposed to be susceptible to sleep deprivation.[9] However, the present study failed to find any significant changes in situation awareness following 24-h sleep deprivation. This study employed a subjective rating scale to assess situation awareness. However, such subjective measures may only provide insight in to how aware the subject felt they were during the task as opposed to how aware they actually were. An individual's subjective assessment may deviate from their actual situational awareness. Self-rating methods of situation awareness may only indicate a subject's confidence in their situational awareness as opposed to their actual awareness, which is proposed to be impaired by sleep deprivation.[2] Results from the present study should be taken with caution as further research employing alternative methods of measurement is advised.

Hand-eye coordination was also found to be susceptible to sleep deprivation, with significant declines in performance observed following 24-h sleep deprivation. Significant impairments were only observed in the dominant hand, presumably due to poor baseline performance levels in the nondominant hand, masking any additional declines in performance as a result of sleep loss. Previous research has consistently found declines in hand-eye coordination and psychomotor performance with up to 30% reductions observed in speed and accuracy as a consequence of sleep deprivation. One study by Taffinder and colleagues[17] examined the effect of sleep deprivation on surgical manual dexterity. They found that surgeons who were deprived of sleep made 20% more errors and took 14% longer to complete tasks relative to those who had a full night's sleep. The present findings suggest that, similar to Taffinder's study among

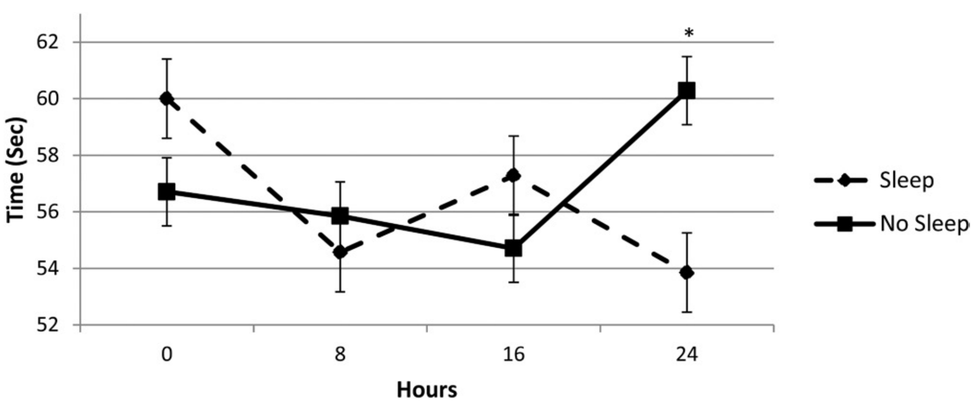

Fig. 4. Hand-eye coordination—GPB: dominant hand (± SE) for the 'Sleep' and 'No Sleep' conditions. $*P < 0.05$.

surgeons, airline pilots' manual dexterity is vulnerable to the effects of short-term sleep loss. Furthermore, neuroimaging findings have suggested that normal functioning of the sustained attention network is altered following a period of sleep loss, which results in greater disengagement from external sensory input, potentially resulting in impairments in hand-eye coordination. The associated decline in sustained attention, as observed with the PVT, may aid in explaining the observed reduction in hand-eye coordination among this study's subjects.

The present study contained several limitations as briefly mentioned in the introduction. Firstly, due to the pilot nature of this study, seven university levels students were recruited to take part in this study. This limited number of young subjects from nonaviation backgrounds may not be reflective of the commercial airline pilot population. Future research should aim to increase subject numbers and recruit commercial airline pilots to confirm and strengthening the findings. Secondly, this study employed analogue, as opposed to direct, measures of airline pilot core competencies, some of which were subjective and not aviation-specific in nature. While it did not directly assess pilots' core competencies, it did measure cognitive functions ranging from cognitive flexibility and working memory to vigilance and hand-eye coordination which have direct implications on those skills required by airline pilots to successfully operate an aircraft. Standardized cognitive tests were employed to provoke and identify changes in psychomotor and cognitive functions. The duties and responsibilities of operating an aircraft undeniably require considerably more complex cognitive functions than those posed by these tests. The deteriorations observed in these particular tests may, therefore, be moderate relative to the actual effects that sleep deprivation may have on cognitive skills required to operate an aircraft. Furthermore, the present study conducted testing sessions every 8 h. As a result, this allowed for a cross-over design, permitting an 8-h sleeping opportunity during the 'sleep' condition and allowing subjects to act as their own controls. Future research should aim to implement more regular testing time points, which will allow for a more detailed indication of potential fluctuations and associated circadian effects throughout the period of sleep deprivation.[2]

Lapses in attention, reductions in vigilance, and decreases in mood and cognitive flexibility were all found following 24-h sleep deprivation and have the potential to negatively impact pilots' performance in the cockpit and contribute to an aviation accident. The results of the present study suggest that subjects were able to maintain a relatively stable performance up to 16 h of continuous wakefulness, which is somewhat replicative of a normal day. However, following this, considerable reductions in mood, fatigue, and certain analogue measures of airline pilot competencies (i.e., cognitive flexibility and hand-eye coordination) became evident, suggesting reductions in optimal functioning following this period of wakefulness. Further investigation using more regular testing time points, employing additional core pilot competencies, and using more aviation-specific tasks will aid in supporting and validating the initial findings of this study.

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