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The Effects of Flash Frequency and Amount of Information in Mitigating the Effects of Fatigue

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ABSTRACT

Fatigue is a crucial factor related to aviation safety and is likely to result in negative impacts in cockpit operation tasks, especially for warning information recognition in emergency situations. The aim of this study was to examine the effects of sleep deprivation induced fatigue on task performance of warning recognition tasks, and how the above effects were moderated by two presentation characteristics of warning information (i.e., flash frequency and amount of information). Nine participants participated in an experiment in which they performed warning recognition tasks under both normal and fatigue conditions. Fatigue condition was induced by one night of sleep deprivation. Flash frequency ranged from 1 to 5 HZ in increments of 1 HZ, while amount of information was indicated by the number of information elements and ranged from 3 to 5. The results indicated that sleep deprivation induced fatigue and overload information amount impaired performance significantly, while flash frequency yielded no significant effect on human performance in fatigue condition. Besides, fatigue interacted with amount of information. Interestingly, in fatigue condition when the information amount raised up to 5, the response time significantly decreased by 100ms compared with 4, while in normal condition the response time increased with the information amount increasing. The findings suggested that fatigue and overload information amount are risk factors of aviation safety, and flash frequency has no mitigating effect under fatigue condition..

Keywords: Pilot fatigue, Sleep deprivation, Decision making ability, Working memory capability, Arousal effect

INTRODUCTION

Mental fatigue is believed to be a gradual and cumulative process and is thought to be associated with a disinclination for any effort, a general sensation of weariness, feelings of inhibition and impaired mental performance. Fatigue has detrimental effects not only on physical and emotional well-being, but also on performance, such as prolonged response time, lowered alertness, poor decision making, and more demanded cognitive processing (Hartzler, 2014; Boyd and Stolzer, 2016; Sallinen et al., 2017). Cognitive and performance deficits due to fatigue are of great concern to pilots (Honn et al., 2017).

Bocca and Denise (2006) showed that fatigue leads to impairment in the disengagement of spatial attention, which may lead to fatal accidents. Besides, situation awareness, which is identified as core competency for safe and effective flight (International Civil Aviation Organization 2016), has consistently been found to be susceptible to fatigue (Caldwell et al., 2004; Sexton, Thomas and Helmreich, 2000; Tucker et al., 2010). Petrilli et al. (2006) also reported that pilots' response time decreased significantly from the beginning to the end of the flight during long-haul flights. Fatigue has also been shown to negatively affect visual performance. Fatigue could decrease binocular convergence (Quant, 1992) and increase visual neglect for centrally and peripherally presented stimulus (Kendall et al., 2006; Rogé, 2003; Russo, 2004).

The problem of pilot fatigue can be even worse, as the development of cockpit technology and automation system allows for longer flights over more time zones, which is more likely to lead to sleep disruption for pilots (Göker, 2018). According to (CFR) Part 121, the maximum duty time of pilots can reach to 16 hours per duty period. These non-"nine to five" shifts may disrupt the opportunity for eight hours of sleep at night in suitable conditions. These disruptions or restrictions of sleep can substantially increase fatigue and impair performance (Petrilli et al., 2006). It is suggested that several nights of sleep restriction result in similar performance impairments with one (or more) nights of total sleep deprivation. In particular, Van et.al (2003) found that participants who obtained 6 hours of sleep per night for 14 days exhibited impairment on par with those who had endured one night of total sleep deprivation. Therefore, in this study, one night of total sleep deprivation is executed to mimic the fatigue condition caused by sleep disruption or restriction in flights.

Recognition of warning information is a key task for safety flight. There have been some evidence suggesting that the performance of such task could be influenced by fatigue. For instance, it is reported that the accident of Colgan Air Flight 3407, which took 50 people' lives, was due to failure of alarm information identification caused by pilot fatigue (NTSB, 2016). However, research on the effect of fatigue on pilot recognition of warning information is lacking. It remains largely unknown how recognition performance is deteriorated by fatigue and whether the above effects would be moderated by warning design factors. Previous evidence suggested that warning design is important to arouse pilot to handle the emergency (ref). Several important design factors of information display, such as the flash frequency of information and the amount of information presented, have been investigated. It is suggested that stimulus that suddenly appear and then move are better in arousing human alertness compared with stimulus that transiently appear but remain stationary (Eagleman and Sejnowski, 2000). Besides, David et.al found that moving objects were perceived more accurately than transiently appeared stimulus (Whitney, Murakami and Cavanagh, 2000). In addition, people have limited working memory capacity of visual information. In normal condition, optimal amount of information elements for maximal working memory capacity could be 3-4 (Luck and Vogel, 1997; Vogel, Woodman and Luck, 2001). In contrast, working memory capacity in fatigue condition could be decreased, but the optimal amount of information elements had not been examined. However, how the above two design factors interfere with fatigue to influence warning recognition performance have less been studied.

In light of this, the present study was conducted to examine the effects of fatigue and how the above effects would be moderated by flash frequency and information amount. The findings from this study can assist the warning information design and improve safety.

METHODS

Experiment Design

This study implemented a three-factor ($2\times5\times3$) within-subjects design, with fatigue level (i.e., normal condition and one night of total sleep deprivation), flash frequency of stimulus (i.e., 1Hz, 2Hz, 3Hz, 4Hz, and 5Hz), and amount of information (i.e., 3, 4, 5) as independent variables in a randomized order. All participants performed all of the 30 trials.

Dependent variables included human performance measured by the task response time and accuracy rate. Response time referred to the time a participant used to identify a target in task interfaces. Accuracy rate was measured as the proportion of correct responses. In this single target tasks, a correct response was recorded when a participant correctly indicated the type and the location of the target. Perceived fatigue referred to the level of the fatigue an individual perceived before the task measured by the Samn-Perelli Fatigue Scale.

Participants

Participants were excluded, if they had previously engaged in sleep deprivation experiments, reported sleep disorders as determined by the SLEEP-50 questionnaire (Spoormaker et al., 2005), took any form of medication known to impact mental alertness (i.e. sleep medication, prescription stimulants, sedating antihistamines, etc.), and experienced menstruation phase (for female participants). Nine postgraduate students in School of Aeronautics in Northwestern Polytechnical University, China (six males and three females, age: 22.7 ± 1.6 years) participated in this study. All of the participants had primary knowledge about aviation and flight. And they were all trained to be qualified participants of this experiment before the formal experiment. They provided written consent prior to participation.

Materials

Apparatus. An all-in-one Lenovo computer (23-inch size with 1600×900-pixel resolution) was used to present the warning information recognition tasks. The screen was positioned at a 90-degree angle with the desk surface, following suggestions in previous studies (Chen et al., 2013; Chourasia et al., 2013). A computer application was developed using MATLAB to present experiment stimuli and record participants' responses.

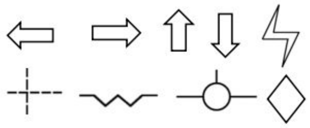

Figure 1: The stimulus displayed on the screen.

Stimuli. Experimental stimuli were designed based on interfaces currently used in many of Chinese cockpits (as shown in figure 1). The types and locations of experimental stimuli appeared randomly on the interface mock-up. Each stimuli above was presented 4000ms.

Experiment Procedures

Each of the participants participated in both normal and fatigue condition. Five participants took the normal condition experiment first and one week later, they took the fatigue condition experiment, and the rest four started with the fatigue condition.

The participants were asked to abstain from alcohol, caffeine, and other drugs for 24 hours prior to test sessions. In the fatigue condition, participants experienced 24-hours sleep deprivation before the formal experimental tests. During the 24h sleep deprivation periods in the laboratory, the room ceiling lights were switched on (~410 lux) and participants were under supervision (mixed sex of experimenter). They were allowed to carry out quiet activities such as reading, writing or discussing. No beverage other than water was provided. The normal lunch and dinner had been supplied to the participants.

In experimental session, participants arrived the laboratory at nine o'clock. A trained research assistant first explained the study's background to the participants and collected their demographic information. Then, participants completed the Samn-Perelli Fatigue Scale (Sam and Perelli, 1982).

The experiment comprised two phases: a 5-min practice phase to get the participants familiarized with study procedures and a 15-trial test phase (5 flash frequency levels $\times$ 3 information amount levels). In each trial, the participants were instructed to focus on a cross on the screen. Later the cross was replaced by a primary display mock-up with experiment stimuli. The participants were asked to confirm the targets as accurately and quickly as possible. When the participants thought they had already confirmed the targets, they need to press F-key for YES and the J-key for NO on the keyboard to simulate the warning information operation in cockpit. The participants executed each task three times. The trials were divided into three blocks based on the information amounts, the sequence of which was counterbalanced. The participants were asked to have a 5-mins break between blocks. The whole experiment could be completed in 45 mins.

Data Analysis

Shapiro-Wilk test was conducted to assess whether the examined variables were normally distributed, and the normality of the performance measures

Table 1. Main effect of fatigue, flash frequency, and information amount on response time (s).

	Descriptive analysis		ANOVA	
	Mean	SLEEP DEPRIVATION	F values	*p* values
NS	1.485	0.315	2.607	0.145
fatigue	1.793	0.603		
1HZ	1.656	0.418	0.625	0.648
2HZ	1.602	0.557		
3HZ	1.642	0.582		
4HZ	1.709	0.497		
5HZ	1.587	0.459		
3	1.585	0.496	**6.782**	**0.007***
4	1.634	0.519		
5	1.698	0.183		

were verified (p > 0.05). The paired t-test was used to examine the difference in sleep deprivation induced fatigue levels between fatigue and normal conditions. Repeated measures analyses of variance (ANOVAs) were used to examine the effects of fatigue, flash frequency and information amount on performance measures, including response time and accuracy of response.

In order to determine if the observed significant differences were practically meaningful, effect sizes quantified by partial-era-squared were calculated. The effect size is the strength or magnitude of the difference between two data sets. Level of significance was set at $\alpha = 0.05$ throughout the analysis.

Results

Results from Fatigue Scales showed that participants in fatigue condition (5.5 ± 0.52) had significantly higher level of fatigue than that in normal condition (1.2 ± 0.42) ($t(9) = -20.146$, p-value < 0.001). This confirmed the effectiveness of one-night sleep deprivation in inducing fatigue.

Table I presents the results of descriptive analysis and ANOVA results on RTs. Information amount was found to have significant effects on RTs ($F(2,16) = 6.782$, $p = 0.007$), while flash frequency and fatigue yielded no effect (Fatigue: $F(1,8) = 2.617$, $p = 0.145$; Flash frequency: $F(4,32) = 0.625$, $p = 0.648$). On average, response time increased by 7.2% as information amount increased from 3 to 5.

Table II presents the result of descriptive analysis and ANOVA analysis results for accuracy rate. Sleep deprivation and Information amount were found to have significant effects on accuracy (Fatigue: $F(1,8) = 11.621$, $p = 0.009$; Information amounts: $F(2,16) = 10.215$, $p = 0.001$), while Flash frequency did not show any significant effect ($F(4,32) = 1.339$, $p = 0.277$). In particular, accuracy rate decreased significantly in fatigue condition compared with normal condition. Accuracy decreased by 9.3% when information amount increased from 3 to 5. Besides, under the 5-stimulus condition, the accuracy rate was especially low (72.7%).

Table 2. Main effect of fatigue, flash frequency, and information amount on accuracy rate (%)

	Descriptive analysis		ANOVA	
	Mean	SLEEP DEPRIVATION.	F values	p values
NS	86.1	13.8	11.621	0.009*
SLEEP DEPRIVATION induced fatigue	67.3	17.5		
1HZ	76.1	15.9	1.339	0.277
2HZ	76.5	17.7		
3HZ	79.4	16.3		
4HZ	76.8	20.6		
5HZ	74.7	20.8		
3	79.9	18.8	10.251	0.001*
4	77.6	17.1		
5	72.6	18.3		

Fatigue interacted with information amount ($F(2,16) = 8.597$, $p = 0.003$). Interestingly, in fatigue condition when the information amount raised up to 5, the response time significantly decreased by 100ms compared with 4, while in normal condition the response time increased with the information amount increasing.

CONCLUSION

In summary, our findings facilitate better understanding the effects of sleep deprivation induced fatigue on information recognition. Specifically, we found that sleep deprivation induced fatigue produced impaired cognition including decision-making capacity and working memory. While the tasks do not require a high level of concentration and vigilant attention, accuracy significantly decreased in fatigue condition. Besides, information amount could be another risk factor for operation. This could be explained by the increased response time and decreased accuracy. These findings suggest that fatigue and information amount are both risk factors for operation, and these negative effects cannot be compensated by the information presentation such as information frequency. To avoid fatigue impairments, pilots' sleep time and flight period should be arranged reasonably. It is suggested that attention should be paid to logical design of the information including information frequency and information amount, so as to mitigate the negative effects of fatigue during flight, especially in emergency situations.

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