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EFFECTS OF PEPPERMINT ODOR ON PERFORMANCE AND FATIGUE IN A SIMULATED AIR TRAFFIC CONTROL TASK

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ABSTRACT

Air Traffic Control (ATC) tasks require a high mental workload with complex cognitive activities. Since the tasks are likely to be fatigue-inducing and may cause aircraft accidents, ergonomics interventions are needed. This study investigated the effectiveness of peppermint odor on improved performance and fatigue while conducting simulated ATC tasks. A total of 16 participants performed ATC tasks using SkyHigh simulation software for two hours in two conditions (with and without peppermint odor). While the simulator was able to record participants' performance during ATC tasks, participants' fatigue development was monitored using an electroencephalograph (EEG), a heart rate monitor (HRM), and psychomotor vigilance task (PVT) apparatus. The results of this study show that the use of peppermint odor significantly ($p < 0.05$) improved simulation performance, based on all simulation indicators. The peppermint odor also significantly ($p < 0.05$) inhibited fatigue development, based on an EEG measure (decline in parietal β), two HRM measures (decline in low frequency power (LF) and increase in high frequency power (HF)), and a PVT measure (10% of the longest time reaction).

Keywords: Air traffic control; Ergonomics intervention; Mental workload; Peppermint odor

1. INTRODUCTION

Air traffic control (ATC) tasks have an important role in aircraft operational safety. Reports indicate that failures in ATC monitoring tasks have caused various aircraft accidents; for example, a near collision between Southwest 440 and Asiana 204 at Los Angeles International Airport in August 2004, an accident involving Comair Flight 5191 in Kentucky in 2006, which resulted in 49 deaths (National Transportation Safety Board, 2007), and a recent aircraft collision between Batik Air and TransNusa in Jakarta Halim Perdana Kusumah Airport in April 2016.

ATC tasks have been reported as being associated with high mental workloads, with complex cognitive activities involved such as planning, evaluation, monitoring, visual perception, memorizing, and decision-making. Such task conditions are likely to cause fatigue and affect ATC performance. Fatigue is reported among the main factors affecting ATC daily performance, and causes various operational errors (Gregory et al., 1999).

Researchers have proposed various interventions to inhibit fatigue development, which can lower cognitive performance (Guo et al., 2015). Proposals include consuming vitamin or mineral supplements, exposure to specific scents during work, or voice or music stimulus. Each

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intervention has advantages and limitations, and each needs more evidence. In this study, the investigation focused on use of a specific scent or odor. Odor exposure using essential oils appears to be more practical than other intervention methods due to its ability to efficiently enter and exit the human body without leaving harmful toxins.

Previous studies have investigated the effects of peppermint odor on performance and fatigue separately (Barker et al., 2003; Raudenbush et al., 2001; Raudenbush et al., 2002; Raudenbush et al., 2009; Warm et al., 1991). For relatively simple cognitive tasks, peppermint is known to be effective in improving signal-detection performance (Warm et al., 1991) and in increasing memory capacity (Moss et al., 2008; Zoladz & Raudenbush, 2005). Peppermint is also effective in maintaining vigilance and in inhibiting fatigue development while driving, based on subjective assessment (Raudenbush et al., 2009). However, no further reports investigate the effectiveness of peppermint odor during highly cognitive tasks. Given that ATC tasks are associated with high risk and complex cognitive loads, this study aimed to investigate the effects of peppermint odor on improving performance and inhibiting fatigue during a simulated ATC task. The choice of peppermint odor was made due to the odor's general acceptance, and it has been reported to be better at affecting performance than cherry (Zoladz & Raudenbush, 2005), jasmine (Zoladz & Raudenbush, 2005), and ylang-ylang (Moss et al., 2008).

2. METHODS

2.1. Experiment Design

The effects of peppermint odor on performance and fatigue during simulated ATC tasks were evaluated using a repeated measures design. There were two experimental conditions: with and without exposure to peppermint odor. Both conditions were used on different days to avoid fatigue-accumulation effects.

2.2. Participants

For each experimental condition, a total of 16 participants were involved. All participants were male, aged between 21 and 28 years (mean 23 ± 1.5 SD). They were recruited from the Institut Teknologi Bandung (ITB) community (Loft & Remington, 2010; Shou & Ding, 2013). Participants were screened to determine that they were healthy, with no flu, cold, or other disease that may interfere with their olfactory abilities. They also needed to have experience of computer use. Participants were asked not to take any supplements, caffeine, alcohol, or cigarettes before experiment days. Informed consent was obtained prior to the experiment, and participants were free to leave the experiment at any time.

2.3. Instruments

The experiments were carried out using a PC-based ATC simulation using SkyHigh ATC software, specifically SkyHigh Approach2 scenario. In this simulation, approach control service tasks were issued. Participants had to provide directions for aircraft that were approaching or had taken off, by monitoring the radar. Directions given to aircraft included altitude, speed, and direction. Traffic conditions were set at the density of 80 aircraft movements per hour. The software was able to monitor participants' performance based on resulting risk levels, number of landed aircraft, and overall simulation scores.

Fatigue development due to mental workload was monitored using electroencephalography (EEG), heart rate monitor (HRM), and psychomotor vigilance task (PVT) apparatus. EEG data were collected using Emotiv EPOC Control Panel v2.0.0.20 software with points measured at F3, F4, T7, T8, P7, P8, O1, and O2 at frontal, temporal, parietal, and occipital lobes. Heart Rate Variability (HRV) data were recorded using Polar RS800CX with 1 Hz sampling rate. A hand-held PVT test using a smartphone was used to measure reaction time before and after performing the simulated ATC tasks. While conducting PVT tests, participants were asked to tap input stimuli that appeared randomly on the screen as soon as possible, by tapping their fingers on the screen.

2.4. Procedure

Prior to joining the experiments, participants were given information on experimental procedures and the equipment to be used. No hint was given about the purpose of the experiment to avoid bias. Participants were given training in using SkyHigh software for 30 minutes. Following the training session, Electroencephalograph (EEG) and HRM were installed, based on the instruction manuals for each apparatus. After an initial PVT measurement (pre-PVT), participants were asked to perform ATC simulation tasks for two hours. Once they had completed the simulation tasks, a PVT test was conducted again (post-PVT) using the same procedure as in the initial test. Peppermint odor was given every 30 seconds using an aromatherapy diffuser. To minimize any learning effect, the order of experimental conditions was counterbalanced. The experimental set up is shown in Figure 1.

Figure 1 Experimental set up

2.5. Data Processing and Analysis

2.5.1. EEG data

EEG data for each brain region were processed using Matlab R2009a. Data obtained from the same brain regions of frontal, temporal, parietal, and occipital lobes were summed. The Power Spectral Density (PSD) of 1-minute sub-samples was calculated using Fast Fourier Transform (FFT) to obtain α, β, and θ wave power. Several indicators that are commonly used to monitor fatigue development due to mental workload were calculated, including the relative power of α, β, θ to total power, β/α, θ/α, and θ/β (Cheng & Hsu, 2011). Changes to the indicators with increasing time were determined as the slope from a linear regression fit.

2.5.2. HRV data

HRV data for a five-minute window were processed using HRV Kubios software to obtain changes to the following indicators: RMSSD, pNN50, LF, HF, and LF/HF. Those indices are commonly used to monitor fatigue development due to mental workload. Similarly, changes to indicators during the experiment were computed as the slope from a linear regression.

2.5.3. PVT data

Data obtained from PVT tests were processed as follows. Fatigue indicators computed included 10% of the longest reaction time, 10% of the shortest reaction time, average reaction time, and number of lapses (reaction time of more than 500 ms). For each indicator, the difference between pre-PVT and post-PVT was computed.

2.5.4. Performance data

Performance data provided by the ATC simulation software included resulting risk levels, number of aircraft landed, and overall simulation scores. The resulting risk levels measured performance in maintaining separation between the aircraft (International Virtual Aviation

Organization, 2009).

2.5.5. Analysis

Data obtained from the experiment condition without exposure to peppermint odor were processed first. Based on these data, indicators with high sensitivity to fatigue were investigated and then selected as the basis for determining the effectiveness of peppermint odor exposure. Any indicator selected should demonstrate a consistent change with increasing time (decreasing or increasing trend) for at least 75% of participant data.

For fatigue-sensitive indicators only, statistical tests were conducted using SPSS 20 to compare differences between the means of the two experimental conditions (with and without peppermint odor) to find any significant effect of peppermint odor. Prior to conducting the tests, normality tests were conducted on the data using the Kolmogorof-Smirnov test. If the data were normally distributed, the test was conducted using the Paired T-test. Otherwise, if data were not normally distributed, the Wilcoxon test was employed.

Correlation coefficients were computed between fatigue-sensitive indicators and ATC performance indicators. For all statistical tests, the significance level was set at $p < 0.05$.

3. RESULTS

3.1. Indicator Sensitivity

As shown in Table 1, a total of 24 EEG indicators, 5 HRV indicators, and 4 PVT indicators were obtained from the experiments. Of all indicators, there were 8 indicators with high sensitivity to fatigue – indicating consistent increased or decreased changes with increasing time – found in more than 75% of participant data. The 10% of the longest reaction time indicator from PVT increased consistently for all participants (100%). Other indicators seemed to have poor sensitivity to fatigue, indicated by a balanced proportion of increasing and decreasing trends with increasing simulation time.

Table 1 Sensitivity of EEG, HRV, and PVT indicators (+/-)

EEG Indicators				
	Frontal	Occipital	Parietal	Temporal
α	10/6	9/7	8/8	8/8
β	8/8	8/8	13/3	6/10
θ	9/7	8/8	5/11	9/7
θ /α	9/7	8/8	5/11	8/8
β/α,	9/7	10/6	12/4	7/9
θ/β	8/8	7/9	5/11	9/7
HRV Indicators				
LF				15/1
HF				1/15
LF/HF				15/1
RMSSD				7/9
pNN50				9/7
PVT Indicators				
10% of longest reaction time				16/0
10% of shortest reaction time				10/6
Average reaction time				14/2
Lapses				14/2

Note: Proportions were determined as the percentages of slopes that were positive (+) or negative (-).
Indicators with shaded cells have high sensitivity to fatigue.

Of the six EEG indicators (α, β, θ, θ/α, β/α, and θ/β) in four brain regions (frontal, occipital, parietal, and temporal), there were two indicators with consistent changes with increasing time, including a positive slope of β relative power in parietal (81.3% participants) and a positive slope of β/α parietal (75% participants). Of the five HRV indicators, three indicators indicated consistent changes with increasing time, including a positive slope of LF (94% participants), a negative slope of HF (94% participants), and a positive slope of LF/HF (94% participants). Of the four PVT indicators, three indicators indicated consistent changes between pre- and post-PVT, including 10% of the longest reaction time (100%), average reaction time (88%), and lapses (88%).

3.2. Peppermint Effectiveness

A sample of EEG data obtained from one participant in two conditions (with and without intervention) is shown in Figure 2. The test of difference indicated that 7 of 11 indicators reported significant differences between the two experimental conditions, without and with peppermint odor exposure (Table 2). The fatigue indicators with significant results are shown in Figure 3. All performance indicators also showed significant differences between conditions without and with peppermint odor exposure; the means are shown in Table 3.

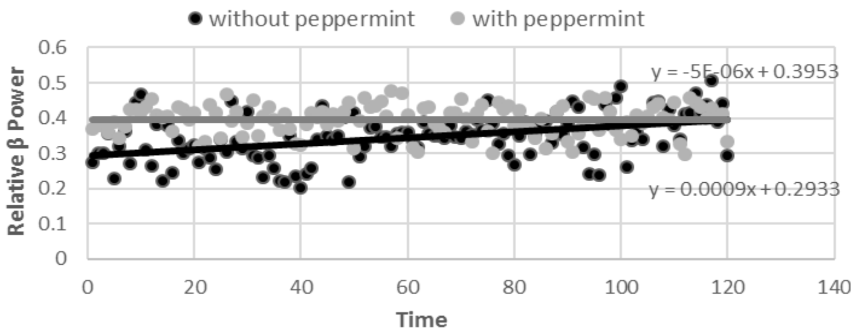

Figure 2 Changes to EEG parietal β with increasing time

Table 2 Results of the difference test

No	Measurement	Indicators	*p* value
1	EEG	Parietal β	0.031*
2		Parietal β/α	0.050
3	PVT	LF	0.022*
4		HF	0.024*
5		LF/HF	0.071
6	HRV	10% longest RT	0.020*
7		Average RT	0.162
8		Lapses	0.718
9	Performance	Risk	0.024*
10		Landed	0.024*
11		Score	0.017*

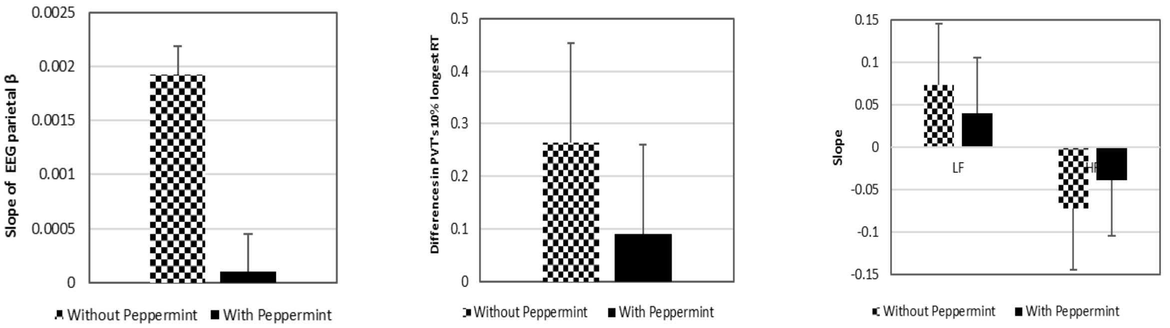

Figure 3 Changes to: (a) EEG parameters; (b) PVT indicators; and (c) HRV LF and HF parameters are significantly affected by exposure to peppermint

Table 3 Results of the difference test based on performance indicators

No	Indicators	Without Peppermint		With Peppermint	
		Mean	Std Deviation	Mean	Std Deviation
1	Risk	8.29	7.89	5.64	6.24
2	Number of aircraft landed	66.88	6.05	71.00	6.29
3	Overall score	513.0	29.05	532.8	30.20

3.3. Correlation between Indicators

Strong correlations were found for four pairs of indicators, including: (1) between LF and HF (both are fatigue parameters); (2) aircraft landed and simulation scores (both are performance indicators); (3) fatigue indicator of EEG β parietal and performance based on resulting risk; and (4) HRV's 10% of the longest RT and performance based on resulting risk (Table 4).

Table 4 Correlation values (r) between fatigue and performance indicators

	β Parietal	HF	LF	10% longest RT	Risk	Aircraft Landed	Simulation Score
β Parietal		-0.076	0.075	-0.076	-0.349*	-0.132	-0.132
HF			-1.00*	0.339	0.107	0.102	0.102
LF				-0.333	-0.113	-0.103	-0.103
10% longest RT					-0.414*	-0.050	-0.050
Risk						-0.080	-0.080
Aircraft Landed							1.00*

Note: Asterisks (*) indicate a significant value at $p<0.05$

4. DISCUSSION

The purpose of this study was to investigate the effectiveness of peppermint odor in inhibiting fatigue development and in improving performance during ATC tasks. We found that peppermint odor was effective, which was indicated by most fatigue and performance indicators. Fatigue indicators included an EEG measure (decline in parietal relative β), two HRM measures (decline in LF and increase in HF), and a PVT measure (10% of the longest time reaction). Performance indicators included resulting risk level, number of aircraft landed, and overall simulation score.

Previous studies have reported the benefits of peppermint odor resulting in lower fatigue levels during driving activity (Raudenbush et al., 2009), although the measurement used subjective measures. In addition, Zoladz and Raudenbush (2005) reported that peppermint significantly affected memory task performance and fatigue. However, their results failed to prove a significant difference in resulting workload. This may be due to the use of NASA TLX, which is a subjective tool for measuring workload.

Interestingly, it was found that all apparatus can be used to monitor fatigue development during ATC tasks, which represents jobs with high cognitive tasks. However, not all indicators were sensitive to fatigue. For EEG, fatigue could be detected through decreases in parietal β relative power. A similar conclusion was obtained by Tatum (2014). However, Sanei (2013) found that a relative increase in β power is also associated with fatigue processes in cognitive tasks that require information processing. Several EEG measures, such as changes in α and θ were unable to detect fatigue during simulated ATC tasks, which contradicts previous results (Brookings et al., 1996; Shou & Ding, 2013). The conflicting results may be due to the differences in simulated tasks compared to the present study. As a result, the characteristics of resulting mental workload were not the same. For HRV measures, changes in LF, HF and LF/HF were sensitive to fatigue. All these indicators were derived from the frequency domain. This result is consistent with Zhao et al. (2010). They reported that mental fatigue resulted in increases in LF and LF/HF, and a decrease in HF. A high mental workload will lead to an increase in sympathetic activity, a decrease in parasympathetic activity, and will disrupt the balance between the two activities.

In addition to inhibiting fatigue development due to mental workload, the use of peppermint aroma is also significantly effective in improving ATC simulation performance. The use of peppermint aroma produces in participants a greater ability both to maintain low risk levels and enable more aircraft to land. Arguably, therefore, the use of peppermint odor is not only able to increase memory capacity (Warm et al., 1991; Zoladz & Raudenbush, 2005), but also to affect other cognitive aspects such as visual perception and decision-making during planning, evaluation, and monitoring.

The present study has demonstrated that improved performance is associated with the inhibition of mental fatigue development. This can be seen from the strong correlations between several mental fatigue and performance indicators. These results are consistent with the statement of Rocco et al. (1999) that ATC fatigue is a factor that affects performance, and the statement of Gregory et al. (1999), which found that fatigue is associated with the occurrence of ATC operational errors. Therefore, the intervention of peppermint odor exposure can be widely implemented in the workplace, particularly for jobs with high mental workloads, such as ATC monitoring tasks.

The main limitation of this study lies in the use of an ATC simulator in the laboratory. The simulator must be able to model the cognitive processes in real ATC activities. The use of simulators cannot perfectly describe real working conditions. Nonetheless, the simulator chosen in this study was the SkyHigh simulator, which can describe cognitive tasks in ATC. In this simulator, participants were required to monitor the aircraft's position continuously, to make a plan for giving orders to maintain smooth air traffic, and to visually perceive the position of the aircraft on the radar. In addition, participants needed to remember the commands already given, as well as the next command. All mental activities existing in ATC tasks were included. Another limitation of this study is the selection of participants. By using participants who are not real air traffic controllers, there are differences in skills. In the present study, participants were provided with training for 30 minutes (Loft & Remington, 2010; Shou & Ding, 2013). The timing of the 30-minute training period was based on the authors' preliminary experiment. To obtain the best performance from the participants, a competition was set up between participants in which a reward was offered to the participant with the best performance.

Ultimately, several issues remain unresolved. Among these issues is the equipment used to release the odor. In this study, peppermint odor was released using a device that was capable of vaporizing peppermint oil instead of using a spray. Both methods create differences in the homogeneity of odor particles in the air. Further research should be conducted to investigate the effects of such homogeneity issues with regard to the effectiveness of peppermint odor.

5. CONCLUSION

The use of peppermint odor was effective in improving the performance of complex cognitive activities in ATC simulation tasks and in inhibiting fatigue development. Fatigue development during ATC tasks can be monitored using changes on an EEG measure (decline in parietal β), two HRM measures (decline in LF and increase in HF), and a PVT measure (10% of the longest time reaction).

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