Does Pre-flight Cigarette Smoking Affect the Military Aviator’s Attention at a Simulated Altitude of 18,000 Feet Created by a Hypobaric Chamber?

Yu-Ming Cheng, M.D.¹, Ching-Hui Loh, Ph.D.², Chien-Bai Sha, M.D.¹, Yi-Chang Wu, Ph.D.³, Hui-Nien Yang, M.D.¹, Wei-An Lin, Ph.D.¹,⁴

Objectives: Cigarette smoking affects performance and attention, but its relationship is unclear. Aviators require sustained, focused attention to maintain aviation safety, but they are frequently exposed to high-altitude environments. In this study, we intended to investigate whether pre-flight cigarette smoking would affect the attention of military aviators at a simulated altitude of 18,000 feet created by a hypobaric chamber. Methods: We evaluated 96 (72 smokers and 24 non-smokers) aviators with the visual search and the incompatibility task. All participants took part in two tasks in a hypobaric chamber at ground level. We randomly chose 48 participants in the smoking group to receive a piece of cigarette with a nicotine dose of 1.0 mg; the other participants in the smoking group (n = 24) received a piece of cigarette with a nicotine dose of 0.1 mg (smoker group 2). After we gave the smoking participants a piece of cigarette, the smokers who received the 1.0 mg nicotine dose were equally divided into two groups (smoker groups 1 and 3; n = 24 each). All aviators except those in smoker group 3 (at ground level for the whole procedure) were subjected to altitude of 18,000 feet. Participants undertook the two tasks again. Results: In smokers, cigarette smoking was found to have a positive effect on reaction time in both visual search and incompatibility tasks, regardless of altitude. The trend was not clear about attitude and attention since no difference was found among smoker group 1 and 3. Conclusion: Cigarette smoking facilitates attention during the visual search and incompatibility tasks in smokers at 18,000 feet of altitude.

Keywords: cigarettes, visual search, incompatibility, hypobaric chamber

Introduction

Cigarette smoking is one of the most prominent worldwide public health problems. The most common cause of death in the world is hypertension, and tobacco use is the second most common cause of death globally. In a report of the 2010 World Health Organization, more than five million people die prematurely each year due to smoking, and this habit is currently responsible for 1 in 10 adult deaths. The prevalence of tobacco dependence remains high because it is a chronic, remitting, and relapsing condition. Nearly 40% of smokers try to quit each year, but only 4%-7% successfully stop smoking in the United States of America [1]. A previous study has shown that flight crews smoke at a much higher rate (50.9%) compared to the ground crews (23.2%) [2]. In a 2004 survey, the smoking prevalence for the Republic of China Air Force aircrew is found to be 45%, which is also higher compared to that of other military servicemen (32.4%) [3].

Smoking among commercial and military aviators is a health hazard in the cockpit. Aviators who are required to abstain before and during their flight, may suffer from a decreased cockpit performance [4]. Cigarette smoking also causes damage to cardiopulmonary function that is critical for performance at high altitudes [5]. Thus, piloting an aircraft is an occupation that requires sustained attention and a healthy body, which may be the most important factor in aviation safety [6].

Nicotine in cigarettes affects cognitive functions including attention. Many studies have shown that in humans, nicotine has a positive effect in improving selective attention [7], visual search performance [8] as well as inspection time [9], and that in rats nicotine administration improves attention [10, 11] and visual signal detection [12].

Another study result shows that cigarette smoking only improves some kinds of attention [13]. Nicotine improves alertness, but does not improve spatial attention in non-smokers [14]. Nicotine does not influence any aspect of attention in people who have never smoked [15]. Furthermore, the nicotine direct effect in improving cognition and attention remains controversial, and the relationship between nicotine and cognitive function is still unclear [16].

Aviators with smoking habits cannot smoke on board of an aircraft. When the altitude of an airplane is below the 18,000-feet level (FL180), whether due to an accident, a forced landing, or a drop in altitude, the key to a safe landing is the aviator’s attention [17, 18]. According to a PubMed search, no study has devoted to investigating the relationship between pre-flight cigarette smoking and attention, either at high altitudes or in a simulated high-altitude environment (e.g., in a hypobaric chamber). In this study, we intended to investigate whether pre-flight cigarette smoking would affect aviator's attention of military servicemen at a simulated altitude of 18,000 feet created by a hypobaric chamber.

Methods

The apparatus

Participants performed the tasks (see below) at ground level on a laptop computer running E-prime version 1.0 while in a hypobaric chamber (1957 Granite Inc., Chicago, Illinois, USA; capacity: eight people). The laptop computer was placed on a table about 60 cm in front of the participant, and the LCD screen was set at the participant's line of vision. Participants used a chin rest to avoid head and body movements. All laptops performed the task smoothly even under the high-altitude conditions of the hypobaric chamber. We used
carbon monoxide (CO) breath-meter (Bedfront Micro Smokerlyzer Breath Carbon Monoxide Monitoring, Rochester, United Kingdom) to measure the recent smoking of the aviators and to distinguish them between the smoker and non-smoker groups.

**The altitude**

According to U.S. Federal Aviation Regulations (FAR, Part § 91.159), FL180 (18,000 feet in Aeronautics, \( \approx 5486.57 \text{ m} \)) is the boundary between the high altitude routes (Jet Route or J-route) and the low altitude routes (Victor airways or V-route) as well as the boundary between visual flight rules (VFR) and instrument flight rules (IFR). In general, the aviator must fly an IFR flight plan above FL180 without special permission from air traffic control (ATC). Furthermore, FL180 is the standard altitude for general physiological training conditions in the U.S. and Taiwan air forces, and the pressure at this altitude is 380 mmHg (0.5 ATM). According to military rules, aviators must successfully complete this training every three years in Taiwan; otherwise, aviators have been grounded until training is completed. To mimic the experience of flight, participants performed attention tasks at a simulated altitude of 18,000 feet created by a hypobaric chamber (a dark environment).

**Study participants**

To prevent medical factors—especially those related to visual problems—from influencing our study, we recruited aviator volunteers from the R.O.C. Air Force Academy to join our study during general physiological training. These participants had the same level of education. As shown in Table 1, we randomly chose 72 male aviators for the smoking groups and 24 male aviators for the non-smoking group. All aviators were about the same age and had the same level of education. Aviators in the smoking group who smoked 10.1 ± 1.6 pieces of cigarettes per day and had been smokers for 5.1 ± 1.9 years. The nicotine yield from the participant preferred cigarette brands was ranged from 0.8 mg to 1.0 mg per cigarette. All participants had excellent visual acuity without correction by any refraction lenses, and no aviator had an eye-related disorders. All participants were licensed aviators who operated military fixed-wing aircraft (the T-34 made by Beech Aircraft [USA] or the AT-3 advanced jet trainer [Taiwan]). Participants were given course credit for their participation. We obtained written informed consent at the beginning of the session and fully debriefed all participants at the end of the session. The institutional review board at Tri-services General Hospital in Taipei approved the study protocol.

**Table 1. Demographic data**

<table>
<thead>
<tr>
<th>Group</th>
<th>Smoker 1</th>
<th>Smoker 2</th>
<th>Smoker 3</th>
<th>Non-smoker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>22.3 ± 0.25</td>
<td>22.2 ± 0.27</td>
<td>22.1 ± 0.28</td>
<td>22.4 ± 0.52</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.5 ± 3.5</td>
<td>172.3 ± 3.1</td>
<td>171.8 ± 3.2</td>
<td>171.3 ± 2.8</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>65.3 ± 5.2</td>
<td>64.3 ± 5.8</td>
<td>64.1 ± 4.8</td>
<td>66 ± 4.2</td>
</tr>
<tr>
<td>Expiratory carbon monoxide (ppm)</td>
<td>12.3 ± 4.2***</td>
<td>12.8 ± 4.1***</td>
<td>12.5 ± 4.6***</td>
<td>1.0 ± 0.5</td>
</tr>
</tbody>
</table>

***p < 0.001. The concentration of expiratory carbon monoxide between smokers and non-smokers were significantly different.
The attention task

We chose the visual search and incompatibility tasks to assess study participant's attention, and these tasks were adapted from Zimmermann and Fimm's Battery for the Assessment of Attention. Both tasks were shown on a 15" LCD computer screen. All responses were recorded.

Visual search is a perceptual task that requires attention and typically involves an active scan of the visual environment for a particular object or feature (i.e., the target) among other objects or features (i.e., distracters). We used the visual search task to measure aviator's visual scanning ability in our study. By displaying a $5 \times 5$ matrix of squares on the computer screen. As shown in Figure 2, each square was nicked on one of its four sides. Participants detected whether the target (a square nicked on its upper side) was present within the matrix as quickly as possible. We presented 100 trials, 50% of the trials contained the target.

The incompatibility task is to assess sensitivity to interference (i.e., incompatibility between the stimulus and response) and the aviator's judgment, capacity, and focused attention [13]. In each trial, an arrow pointing to the right or the left was presented on the right or the left side of a fixation point. Participants reacted to the arrow direction by pushing the “J” key with their right index finger when the arrow pointed right and the “F” key with their left index finger when the arrow pointed left, regardless of whether the arrow appeared to the left or right of the fixation point. Therefore, when the arrow was displayed on the side that corresponded to the answering hand, the arrow and side were compatible. Conversely, an incompatibility arose when the hand required to type and the arrow direction was on opposite sides. Participants did 60 (15 compatible and 15 incompatible) trials in each visual hemi-field.

The tasks began once the participants' eyes had adapted to the darkness, and the order of the tasks was counterbalanced between participants, who were tested together (each with his own computer) in a dark hypobaric chamber to simulate the flight. To diminish practice effects, we designed all task signals to appear randomly on the computer screen.

The procedure

As shown in the schematic presentation of Figure 1, all participants arrived at the hypobaric chamber center before 10:00 p.m. the day before the test. They were requested to abstain from eating irritating food and drinking caffeine-containing beverages, or alcohol.

At 8:00 a.m. on the testing day, the participants who smoked habitually stopped smoking their own cigarettes two hours before the task [19]. During those two hours, we showed partici-
Smoking Facilitates Attention at FL180

Participants were randomly selected from the smoking group to receive a cigarette with a nicotine dose of 1.0 mg, whereas the other smoking participants (n = 24) received a control cigarette with an ineffective nicotine dose of 0.1 mg (smoker group 2; Table 1) [20]. We randomly divided the smokers who received 1.0 mg of nicotine into two groups (smoker groups 1 and 3; n = 24).

Except for smoker group 3, we divided all participants (n = 72) into nine groups (the capacity of the hypobaric chamber is eight people) and randomly selected eight participants from each group. Smoker groups 1 and 2, as well as the non-smoker group re-entered the hypobaric chamber. The procedure followed the Type Six Hypobaric Chamber Flight of R.O.C. Air Force Aerospace Physiology Program, the same program used by the U.S. Air Force. To monitor any feelings of discomfort or participant problems, we elevated the altitude to the FL50 at 2,000 feet per minute (2.5 minutes) followed by a return to ground level at the same rate. If participants felt at ease with this procedure, we elevated the altitude to reach the FL180 at a rate of 2,000 feet per minute. The altitude reached FL180 after 9 minutes. At the 15-minute mark (10:45 a.m.), the participants performed the second task (recorded as Test 2) again. After finishing the two tasks, we returned the participants to ground level conditions at the same rate. The entire procedure took about 30 minutes per group.

Smoker group 3 re-entered the hypobaric chamber, but the altitude was set at ground level during the entire procedure. After 15 minutes (10:45 a.m.), they completed the second task again (recorded as Test 2) at ground level.

**Statistical analyses**

A general linear model (GLM) and Tukey’s HSD compared the average reaction time of the four groups at ground level and at FL180 level; an ANOVA compared the CO concentration among four groups. A two-sided t-test assessed whether Test 1 and Test 2 were significantly different from each other.
each other \((\alpha = 0.05)\). We analyzed all data with Statistical Package for Social Science (SPSS, Inc, Chicago, Illinois, USA) software version 15.0 for Windows. The differences between the groups were considered significant if \(p\)-values were smaller than 0.05.

## Results

### Demographic data

We did not find significant differences among smoker group 1, smoker group 2, smoker group 3, and the non-smoker group with regard to age, height, and body weight. The concentration of expiratory carbon monoxide between smokers and non-smokers were significantly different \((p < 0.001)\), but we did not find differences among the smoker subgroups (Table 1).

### Visual search task

Table 2 reports the visual search task data. We observed significant differences between all groups with regard to reaction time at Test 1 \((F(3, 92) = 22.438, p < 0.001)\). A post-hoc test showed that all smokers groups were significantly slower than the non-smoker group (Tukey's HSD test, \(p < 0.001\)), however, we did not find a difference among smoker groups 1, 2, and 3. We found significant differences among all groups at Test 2 \((F(3, 92) = 213.69, p < 0.001)\). The average reaction time of smoker group 2 and the non-smoker group was significantly slower than smoker groups 1 and 3 (Tukey's HSD test, \(p < 0.001\)). We did not find a difference between smoker groups 1 and 3. The reaction time of smoker group 2 was significantly slower than the non-smoker group \((p < 0.001)\).

Figure 3 illustrates the change of reaction time between Test 1 and Test 2. A paired t-test analyzed the change of each group between Tests 1 and 2. The average reaction time for the non-smoker group did not change significantly between Tests 1 and 2. Conversely, the average reaction time of smoker groups 1 and 3 was significantly faster at Test 2 compared to Test 1 \((p < 0.001)\), whereas for smoker group 2, the average reaction time at Test 2 was significantly slower than Test 1 \((p < 0.001)\).

### Table 2. Average reaction time (msec) in the visual search and incompatibility task.

<table>
<thead>
<tr>
<th></th>
<th>Visual search task</th>
<th>Incompatibility task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test 1</td>
<td>Test 2</td>
</tr>
<tr>
<td>Smoker group 1</td>
<td>1580 ± 209.6***</td>
<td>851 ± 183.6</td>
</tr>
<tr>
<td>Smoker group 2</td>
<td>1596 ± 194.8***</td>
<td>1877 ± 178.3+++</td>
</tr>
<tr>
<td>Non-smoker group 1</td>
<td>1272 ± 158.1</td>
<td>1156 ± 167.7+++</td>
</tr>
<tr>
<td>Smoker group 3</td>
<td>1588 ± 199.1***</td>
<td>770 ± 160.2</td>
</tr>
<tr>
<td>Smoker group 1</td>
<td>512 ± 55.9***</td>
<td>328 ± 49.8</td>
</tr>
<tr>
<td>Smoker group 2</td>
<td>512 ± 61.0***</td>
<td>625 ± 44.1+++</td>
</tr>
<tr>
<td>Non-smoker group 1</td>
<td>424 ± 44.3</td>
<td>404 ± 39.4+++</td>
</tr>
<tr>
<td>Smoker group 3</td>
<td>515 ± 49.1***</td>
<td>281 ± 59.9</td>
</tr>
</tbody>
</table>

*** \(p < 0.001\). In the two tasks at Test 1, the average reaction time between smokers and non-smokers was significantly different.

+++ \(p < 0.001\). In the two tasks at Test 2, the average reaction time of smoker group 2 and the non-smoker group were slower compared to smoker groups 1 and 3. Smoker group 2 was slower than the non-smoker group.
Incompatibility task

Table 2 reports the data for the incompatibility task. We observed significant differences in reaction time among all groups at Test 1 ($F_{(3,92)} = 21.118, p < 0.001$). The average reaction times for smoker groups 1, 2, and 3 were significantly slower compared to the non-smoker group (Tukey’s HSD test, $p < 0.001$); however, we did not observe differences in reaction time among smoker groups 1, 2, and 3. At Test 2, we observed significant differences in the reaction time among all groups ($F_{(3,92)} = 286.67, p < 0.001$). The average reaction time of smoker group 2 and the non-smoker group were significantly slower than smoker groups 1 and 3 (Tukey’s HSD test, $p < 0.001$); however, we found no differences between smoker groups 1 and 3. Smoker group 2 was significantly slower than the non-smoker group (Tukey’s HSD test, $p < 0.001$).

Discussion

Mancuso et al. in 2001 showed that participants who have consumed a piece of cigarette (0.9 mg of nicotine) respond faster in an eye-movement task [13]. Furthermore, they showed that although nicotine can improve a participant’s alert state, it has no effect on incompatibility and visual
search tasks [13]. With the exception of the low-pressure and dark environment of the hypobaric chamber, we used the same procedure to evaluate performance associated with the incompatibility and visual search tasks. Our results are not compatible with those obtained by Mancuso et al. [13]. In our study, a 1.0 mg-nicotine dose had a positive effect on reaction time in both visual search and incompatibility tasks at Test 2, regardless of altitude. Several possible reasons may explain this difference. First, Mancuso et al. in 2001 studied only 10 participants, far fewer than our study (n = 96) and who had been deprived of tobacco for three hours [19]. Second, smokers may have poor night vision, especially after recently smoking [21]. In our study, the participants were tested in a dark hypobaric chamber to simulate flight, and we will set the environment in light or dark to evaluate differences between lighting conditions. And third, the simulated altitude or atmosphere may also factor into this result.

We found that the average reaction time of smokers was slower than non-smokers in both tasks at Test 1. After smoking their assigned cigarette, smoker group 2 (0.1 mg-nicotine dose) was significantly slower than smoker groups 1 and 3 (1.0 mg-nicotine) as well as the non-smoker group in both tasks at Test 2. The reaction time of smoker groups 1 and 3 was faster than non-smoker, so cigarette smoking (1.0 mg-nicotine dose) improved visual search and incompatibility task at Test 2 significantly. Because smoker group 2 received an ineffective dose of nicotine (0.1 mg-nicotine dose), the reaction time of them was slower than smoker groups 1 and 3 at Test 2. All participants abstained from cigarette smoking for two hours before participating in our study. But, the reaction time was not significantly different

Figure 4. Reaction time for the incompatibility task *** p < 0.001
among the smoker groups at Test 1. After 15 minutes, the Test 2 reaction time for smoker group 2 was slower than at Test 1 on both tasks. Perhaps nicotine withdrawal occurred at Test 1 but was counterbalanced in each smoker group. After 15 minutes, nicotine withdrawal was probably more obvious, especially for smoker group 2, who received cigarettes with an ineffective 0.1 mg-nicotine dose. The nicotine withdrawal may have had the greatest effect on the results of the smoker group 2 at Test 2.

Nicotine withdrawal syndrome is classified under code 292.00 in the DSM-IV-TR and its symptoms include anxiety, difficulty concentrating, irritability, and restlessness, all of which can affect performance during flight [22]. Determining when smokers are experiencing nicotine withdrawal is difficult, although performance impairments have been observed after a few hours of cigarette abstinence [23, 24]. Moreover, withdrawal-induced performance deficits, including those related to attention, are not typically seen within two hours of tobacco deprivation [19]. To prevent the influence of nicotine withdrawal syndrome on the evaluation of attention, we deprived participants of tobacco for only two hours. In future study, nicotine dependence severity (FTND), nicotine withdrawal measure, and expired CO data collection after the task must be considered.

Whether altitude influences the results of the visual search and incompatibility tasks is an important problem. Although the difference was not significant, we found that smoker group 3 (1.0 mg-nicotine dose at ground level) responded faster than smoker group 1 (1.0 mg-nicotine dose at FL180) on the visual search and incompatibility tasks of Test 2. Furthermore, the reaction time at Test 2 was faster than Test 1 for the non-smoker group. Thus, although change in altitude may not have had any effect on attention statistically speaking, the trend is clear. Because we collected only the reaction time before participants smoked, we could not separate the relationship between altitude and attention. Although this is our study limitation, aviators cannot smoke on board an aircraft in reality. Our study design reflects the reality of being an aviator. To investigate whether altitude influences attention more clearly, we may add an additional study to compare reaction time at ground and FL180 after receiving a cigarette and increasing other aspects of attention in the future. Another study limitation with the design is failure to test the effects of cigarette on the non-smoker group. It has ethical issues, and other material (e.g., nasal spray, nicotine patch) cannot reflect actual smoking effect in our study [25].

Hypoxia is another possible phenomenon that influences attention [26]. In Test 2, smoker groups 1 and 2 as well as the non-smoker group were slower at FL180 compared to smoker group 3 at ground level. Although no significant differences were found in each group compared to smoker group 3, this trend was visible in two tasks (Figure 3 and Figure 4). In general, people need to be provided oxygen when the altitude is higher than FL100. If people are not provided oxygen above this level, they can suffer from anoxia, ability loss, and death. Time of useful consciousness (TUC), also referred to as effective performance time (EPT), is an important index for determining levels of hypoxia [27]. Generally speaking, TUC is relatively shorter with increases in body activity or altitude. Various altitudes have corresponding average TUC times. At FL180, oxygen pressure is 79 mmHg and TUC is approximately 20-30 minutes. In other words, a person will lose consciousness after about 20-30 minutes at FL180. In this study, each task required 2-3 minutes (5-6 minutes in total). Therefore, TUC likely had no influence on our results. TUC length, however, varies from
person to person and is primarily determined by pressure height. Individual differences are difficult to exclude, and personal tolerance, body activity, and anoxia can influence TUC.

In the study, reaction time results show that non-smokers were faster than smokers after two hours of tobacco deprivation at ground level. Smoking a piece of cigarette with 1.0 mg of nicotine (smoker group 1 and 3) facilitated better reaction times at Test 2. But smoking a piece of cigarette with 0.1 mg of nicotine (smoker group 2) decreased reaction time on the visual search and incompatibility tasks at a simulated altitude of 18,000 feet created by a hypobaric chamber. The trend was not clear about attitude and attention since no significant difference was found among smoker group 1 and 3 at Test 2.

Conclusion

In our study, we conclude that cigarette smoking had a positive effect on reaction time in both visual search and incompatibility tasks in smokers, regardless of altitude. Whether altitude affects attention needs additional study.

To maintain aviation safety, we suggest that a government agency like the Federal Aviation Administration promotes smoking cessation in aviators. This promotion must be careful and implemented step-by-step to prevent nicotine withdrawal syndrome after boarding. Although the pilots who smoke may be healthy physically, they must quit smoking to maintain perfect attention. Although our participants are military aviators, these findings are equally critical for all jobs that require good attention.

Acknowledgements

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References

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