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Effects of mild hypoxia in aviation on mood and complex cognition

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ABSTRACT

Thirty six volunteer air force personnel were sequentially exposed in a randomized balanced order in a hypobaric chamber to 30 min of baseline (sea level) and mild hypoxia induced by a specified altitude (sea level, 8000 ft and 12,000 ft), followed immediately by breathing 100% oxygen from an oro-nasal mask. Mood and complex cognition were assessed. Analysis of variance indicated that mood (fatigue and vigour) remained the same at 8000 ft but fatigue was increased ($p = 0.001$) and vigour reduced ($p = 0.035$) at 12,000 ft and was restored by supplementary oxygen. Complex cognition was not significantly altered by the test conditions. The results of this study do not support prior evidence that mild hypoxia equivalent to either 8000 or 12,000 ft, impairs complex cognition, but suggests that some aspects of mood may be affected at 12,000 ft and can be restored by breathing 100% oxygen.

1. Introduction

This paper questions the appropriateness of designing pressurised aircraft to maintain a cabin pressure equivalent to about 8000 ft (mild hypoxia). The reason for asking this question is that numerous studies have suggested that some aspects of complex decision-making by pilots may be impaired due to mild hypoxia, especially in novel or unusual situations such as emergencies. It is possible that mild hypoxia may be an under-recognised latent flight safety hazard that may have contributed, and possibly will continue to contribute to root causes for aircraft accidents. As far as the authors are aware, this has never been proposed as a possible contributing factor in the recent Malaysian MH370 aircraft disaster mystery, nor the Air New Zealand Flight 901 Mt Erebus disaster in Antarctica, to take two prominent examples. We believe it is remiss to exclude the possibility of mild hypoxia as a latent pre-condition for aviation disasters such as these.

The question is not new for aviation medicine specialists - as far back as 1984 Ernsting (1984) questioned the 'appropriateness' of the generally accepted aviation threshold of 10,000 ft before the use of supplementary oxygen or cabin pressurisation was mandatory. The question has largely been ignored by aircraft manufacturers and aviation industry regulators. It is worth asking again because the commonly accepted and regulation '10,000 ft threshold' could be construed as irresponsible if there were widespread agreement, based on evidence such as that summarised below and in the present study, that a lower threshold such as 8000 ft, were more appropriate as a guide for future aircraft design. This could have major implications for future aircraft design technology and cost, since it could mean that a fuselage strength/rigidity capable of safely withstanding a greater internal/external pressure gradient would be needed. A design goal in many newer aircraft, although not all, is to lower the 'cabin altitude' with the aim of improving passenger and crew comfort and preventing exposure to mild hypoxia, altitude sickness and barotrauma.

Most routine commercial and military pressurised aircraft maintain a cabin pressure equivalent to about 8000 ft (2438 m). National and supra-national aviation authorities allow pilots to fly unpressurised without the requirement for supplemental oxygen to an altitude of 10,000 ft (3048 m) (Civil Aviation Authority Australia (2011)). In the United States this can be up to 14,000 ft (42678 m) for 30 min (Federal Aviation Administration, 2011). Aircrew operating below 10,000 ft are not generally considered to be at risk of developing significant symptoms of hypoxia (Kupper et al. 2011). Aviation medicine texts often emphasise the benign nature of operating below this altitude (Pickard, 2008) and some advisory documents even reassure aircrew that 'significant effects of altitude hypoxia do not occur in the normal healthy pilot below

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12,000 ft' (Federal Aviation Administration, 2013). Much of this acceptance is based on a literature review of papers published between 1950 and 1963 (Tune, 1964).

The literature about the presence and significance of cognitive impairment in pilots at moderate altitudes (i.e. between 6000 and 14,000 ft and corresponding levels of mild hypoxia) is controversial. The earliest studies of mild hypoxia reported that learning in complex tasks (such as a manikin task) at altitudes as low as 5000 ft (1500 m) was slower than at sea level (Denison et al., 1966) and that exposure to hypoxia equivalent to an altitude of 8000 ft could affect complex, multiple, time-shared tasks, or simulated flight activities (Frisby et al. 1973; Gold and Kulak, 1972). Subsequent studies reported that well-learned cognitive, vigilance and perceptual-motor performance tasks were not affected (Fowler et al. 1985; Paul and Fraser, 1994; Hewett et al. 2009). Others have reported that the performance of novel and complex cognitive tasks involving memory and multiple demands may be impaired (Fowler et al. 1985; Farmer et al. 1992; McCarthy et al. 1995; Legg et al. 2014), including procedural errors in simulated flight (Nesthus et al. 1997). Cable (2003) reported the occurrence of four adverse aircraft safety reports (out of 27 such reports in the Australian Defence Force during 1990–2001) due to hypoxia at altitudes below 10,000 ft. This is consistent with real-world observations of acute symptoms of hypoxia at altitudes below 10,000 ft in operational helicopter crew (Smith, 2007) and impaired sleep quality in aircraft cabins at 8000 ft (2438 m) (Muhm et al. 2009). Coote et al. (2010) have pointed out that though the routine cockpit tasks of pilots can be performed competently 'it would appear that at present cabin altitudes, the learning of a novel task is impaired'.

In a recent systematic review of the effects of hypoxic hypoxia at moderate altitudes on cognitive and psychomotor performance, Petrassi et al. (2012) reported increased reaction time on orientation tasks from 7000 ft (2134 m), learning impairment in a manikin test at rest at 8000 ft (2438 m), increased errors in arithmetic and decision making by 12,000 ft (3658 m) with working memory affected as low as 9136 ft (2785 m) in some studies but not until 14,000 ft (4268 m) in others. The review concluded that performance on simpler tests appeared to be more readily preserved with altitude, for example for finger tapping, and simple reaction time. The authors interpreted the preservation of simple tasks and decrements in more complex tasks as indicating that at 'mild' levels of hypoxia, psychomotor performance is maintained whilst truly cognitive functions are affected. They also suggested there was a greater likelihood of decrements in cognition with greater complexity (e.g. in terms of decision errors in complicated flight situations) for a given level of mild hypoxia, and that subtle undetected complex cognitive deficits can be dangerous and unforgiving in terms of accident causation preconditions. It also seems likely that the effects of mild hypoxia on mood will be important, but in most previous studies mood has not previously been included and reported.

Some of the laboratory studies mentioned above were poorly controlled or un-blinded and included relatively straightforward tests of complex cognition that were not well related to aspects of cognition that are required in real-world conditions. Some have used a hypoxic gas mixture at sea level (i.e. normobaric hypoxia) to simulate hypoxia at an altitude equivalent to 2438 m (8000 ft) (i.e. hypobaric hypoxia). Since Baumgardner et al. (1980) have shown that there are no differences in responses to hypoxia imposed by these two different methods, the results of normobaric hypoxia studies (e.g. Legg et al. 2014) are likely to be equally applicable for hypobaric hypoxia i.e. for the mild hypoxia to which aircrew are exposed in aircraft cabins. Nevertheless, in order to improve face validity, there is merit in conducting similar studies in a hypobaric chamber. Thus, despite the findings of Petrassi et al.'s review, there is still a need for a well-controlled and blinded hypobaric chamber laboratory study of mild hypoxia that examines mood and includes tests of complex cognition that have a higher level of real-world face validity.

The present study was designed to be well controlled, to be fully blinded and to include tests of complex cognition that could justifiably be considered to include aspects of complex cognition required in piloting large long haul aircraft. Specifically, it examined the effects of exposure of air force personnel to hypobaric hypoxia equivalent to altitudes of ground level, 8000 ft and 12,000 ft. Mood and complex cognition were assessed using a battery of psychological tests that drew on some of the complex cognitive capacities that are common in a wide variety of real-world situations by pilots. We hypothesised that mood and performance for the complex cognition tests were likely to be affected by exposure to altitude on account of their complexity and novelty and because they involved multiple demands. The study also explored the efficacy of a potential practical 'simple fix' for any potential effects of exposure to mild hypoxia (i.e. the provision of supplementary oxygen via an oro-nasal mask during exposures to 12,000 ft), in which it was hypothesized that mood and complex cognition test performance would be restored to normal levels.

2. Methods

2.1. Participants and study design

The study protocol was approved by the Massey University Human Ethics Committee and performed according to the Declaration of Helsinki. Thirty six Royal New Zealand Air Force personnel aged between 18 and 40 years volunteered and participated. All were male, non-smokers and had no colour blindness as this could have influenced performance on some of the tests. Twenty four were base staff with experience of air operations. Twelve were active aircrew. Each participant attended two sessions, each separated by at least two days. The first session was for briefings, chamber and procedural familiarisation and practicing the mood and cognitive tests. The second session was the main study session in which participants undertook three hypobaric chamber exposures which included performing seven mood and six cognitive tests at three separate altitudes: ground level (0 ft), 8000 ft and 12,000 ft, and also with supplementary oxygen at 12,000 ft in a hypobaric chamber.

The first session started either in the morning at 0830 h or afternoon at 1330 h. It included briefings, familiarisation with the hypobaric chamber and oxygen mask and four practices of the mood and cognitive tests, with the following timings for the start of each activity. 0 min: briefing about the study and protocols, provision of prior informed written consent, chamber familiarisation, fitting and use of oxygen mask; 30 min: enter chamber and first practice at ground level; 60 min: simulated ascent to altitude; 66 min: resting at simulated altitude; 75 min: second practice (at simulated altitude); 105 min: don oxygen mask and breathing 100% oxygen (still at simulated altitude): 114 min: third practice whilst wearing mask and breathing 100% oxygen (still at simulated altitude); 144 min: descent to ground level, doff oxygen mask; 150 min: fourth practice (at ground level), exit chamber; 180 min: debrief. All of the first session was conducted at ground level, but included a simulated ascent and descent. This lasted 6 min and was effected by cross-venting the chamber so that the participants became familiar with the effects of the cooling and warming and noises of the hypobaric chamber and so that these effects would become less likely to influence their test performance in the main session. It also formed part of the experimenters' strategy to maximise the chances that the participants remained 'blind' to the altitude exposures in the main session. During the first and second practices, participants were allowed to interact with experimenters and receive guidance, as-