The effects of a combination of hypoxia and positive pressure breathing on an indicator of aircrew operational effectiveness

By Alasdair J Mort

QinetiQ

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Contact information:
QinetiQ Centre for Human Sciences
Room 1011/A50 Building
Cody Technology Park
Ively Road, Hampshire, GU14 0LX, UK
E-mail: ajmort@QinetiQ.com

Abstract

In the event of rapid decompression to altitudes in excess of 40,000 feet, 100% oxygen must be supplied to aircrew at a positive pressure in order to prevent hypoxia. However, positive pressure breathing (PPB) with an oronasal mask represents a considerable physical stress in itself.

The aim of the present study was to examine the effects of a combination of a given level of normobaric hypoxia (P_{IO2}=67 mmHg) and/or PPB (45 mmHg) on the performance of eight male subjects (22 to 34 years old) using an indicator of operational effectiveness (NASA Multi-Attribute Task Battery).

Two types of lower body counter-pressure protection were applied (standard and full coverage anti-G trousers) in conjunction with a range of pressure ratios established between anti-G trousers and chest counter-pressure garment (1:1 for standard coverage, and 1:1, 1.5:1 and 3:1 for full coverage).

PPB at 45 mmHg was found to represent a considerable distraction, in particular to subjects' hand-eye co-ordination ($p<0.05$). Hypoxia was also found to impair performance ($p<0.05$), and the effects of hypoxia and PPB appeared to be additive on one aspect of the task.

The results also demonstrated that, under hypoxic conditions, the full coverage anti-G trousers inflated to three times breathing pressure provided the greatest preservation of Tracking ability compared with all other garments and inflation ratios ($p<0.05$).

Introduction

Ascent to altitude results in a fall of atmospheric pressure and a simultaneous drop in the partial pressure of oxygen in air. Exposure to a reduced partial pressure of oxygen results in hypoxia, which is associated with a reduction in mental and physical performance.

Upon decompression to altitudes below 40,000 ft, hypoxia can be prevented by increasing the concentration and hence the partial pressure of oxygen in the lungs by the use of oxygen equipment. Above 40,000 ft, hypoxia can only be prevented by supplying 100% oxygen to the respiratory tract at a pressure greater than ambient.

This positive pressure breathing (PPB) acts to maintain a physiologically acceptable inspired partial pressure of oxygen so that mental and physical capacity are preserved.

PPB imposes penalties (including distension of the upper respiratory passages, spasm of the eyelids and respiratory and cardiovascular stress), which limit

the level and duration that can be tolerated. The respiratory and cardiovascular penalties can be reduced by the application of counter-pressure to the chest and to the legs and abdomen.

Currently, two varieties of lower body counter-pressure exist. Standard coverage anti-G trousers provide approximately 30% bladder coverage of the lower body, but do not provide optimal support during PPB (1,2). Full coverage anti-G trousers (FCAGT) provide approximately 90% bladder coverage of the lower body. FCAGT have been demonstrated to provide better cardiovascular support than standard coverage anti-G trousers (4,5). Raising the inflation pressure of FCAGT relative to breathing pressure provides even greater cardiovascular support (6).

The vast majority of studies investigating such penalties have focused upon the *physiological effects* of PPB rather than their *operational consequences*. Hence the aim of this study was to examine further the effect of a given level of PPB and hypoxia on an indicator of aircrew performance (i.e. operational effectiveness).

The study would also allow a re-examination of the protection afforded by standard and full coverage anti-G trousers, including several pressure ratios established between FCAGT and the chest counter-pressure garment (CCPG).

Methods

Eight male subjects (aged 22 to 34 years) volunteered to take part in the study following medical examination and Local Research Ethics Committee approval. All subjects had considerable experience of hypoxia and PPB prior to participation in the study.

The subjects wore an R.A.F. P/Q oronasal mask, Mark 10B helmet and aircrew coverall. In addition, the subjects wore one of two types of counter-pressure assembly. The standard coverage assembly consisted of a partial pressure jerkin and standard coverage anti-G trousers. The full coverage assembly consisted of CCPG and FCAGT.

The subjects completed 10 conditions encompassing combinations of hypoxia or normoxia (i.e. no hypoxia), PPB at 45 mmHg or no PPB, and standard or full coverage counter-pressure with pressure ratios between FCAGT and CCPG of 1:1, 1.5:1 and 3:1.

PPB at 45 mmHg was applied by decompressing the hypobaric chamber to produce the required pressure differential (i.e. 45 mmHg) across its wall. Figure 1 shows the position of a subject within the chamber performing the task.

Figure 1. Subject performing the task within the hypobaric chamber

Appropriate breathing gases were supplied to the subject at ground level in order to simulate a rapid decompression followed by exposure to 18,500 ft. Rapid decompression was mimicked by inhaling two ‘washout’ breaths of 100% nitrogen, which represented no more than 50% of each subject’s total lung volume. Subjects were then switched to an hypoxic gas mixture (9.4% oxygen in a balance of nitrogen) designed to deliver an inspired partial pressure of oxygen of 67 mmHg.

The test of operational effectiveness chosen was the NASA Multi-Attribute Task Battery (MATB) (3), which was originally designed to provide a benchmark set of tasks for use in a wide range of laboratory studies of operator performance and workload. MATB incorporates tasks analogous to activities that aircrew perform in flight while providing the freedom to use non-pilot test subjects. Figure 2 illustrates the typical screen that the MATB displays to subjects.

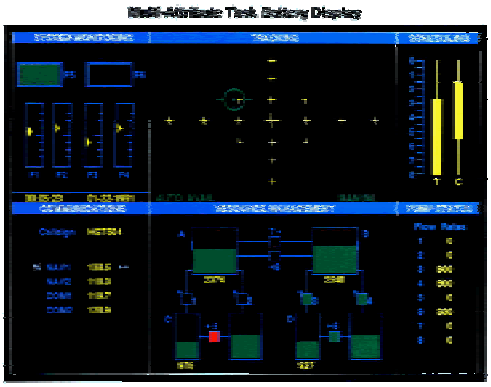

Figure 2. Typical MATB display screen

The subjects performed two elements of the MATB, namely a Tracking task and a Monitoring task. The Tracking task was employed to imitate the demands of manual control and involved subjects tracking a target using a joystick in their dominant hand. The Monitoring task measured subjects' reaction times on a series of gauges and warning lights. The subjects were trained prior to the study, until stable performance had been achieved on both tasks, assigning equal importance to each.

The stress, whether PPB, hypoxia, or a combination of both, was applied for a maximum of two and a half minutes. This commenced precisely 30 seconds after the subject had begun the MATB. On termination of the stress, subjects performed the MATB for one further minute with no stress applied.

Results

The subjects were deemed to have made a slow response if their Tracking or Monitoring value was greater than the control value obtained at the end of their initial training (i.e. the data was normalised for performance).

Statistical analysis revealed that hypoxia, by itself, had a significantly detrimental effect on the Tracking task ($p<0.05$) but not on the Monitoring task ($p>0.05$). PPB, alone, also had a significant effect on the Tracking task ($p<0.05$), but again it did not affect the Monitoring task ($p>0.05$).

The interference to the Tracking task caused by PPB alone was found to be greater than that caused by hypoxia alone ($p<0.05$). When combined, hypoxia and PPB had an additive effect on the Tracking task but not on the Monitoring task.

The disruption to the Tracking task also persisted in the minute of recovery post removal of PPB. Some of the subjects reported feeling subjectively worse upon removal of PPB, particularly whilst wearing the full coverage assembly inflated to three times breathing pressure. However, performance on the Tracking task during recovery was no worse in the 3:1 condition under hypoxia when compared with all other garments and pressure ratios.

Under normoxic conditions, the full coverage assembly inflated to 1.5 times breathing pressure provided the greatest preservation of performance on the Tracking task compared with the other assemblies ($p<0.05$).

Under hypoxic conditions, the full coverage assembly inflated to three times breathing pressure provided the greatest preservation of performance on the Tracking task ($p<0.05$).

There was no significant difference between counter-pressure assemblies as far as the Monitoring task was concerned for either normoxia or hypoxia ($p>0.05$).

Discussion

The Tracking task was affected by both PPB and/or hypoxia, with PPB exerting the greatest detriment to performance. The Monitoring task was not affected by PPB or hypoxia, alone or combined.

The results provide further evidence that PPB disrupts cognitive performance. In this study, distraction by PPB was significantly greater than the interference imposed by hypoxia alone. PPB could even be considered to be a secondary task to performing the MATB and hence a further distraction, a result that is in contrast to a previous study where there was no evidence of distraction even up 80 mmHg PPB (7). However, that study utilised a different indicator of operational effectiveness to that employed in this study, indicating that the outcome of the application of PPB stress depends very much upon the task chosen for subjects to perform.

During PPB combined with hypoxia, the full coverage anti-G trousers inflated to three times breathing pressure appeared to provide the greatest preservation of performance on the Tracking task, although performance remained poorer than control values ($p<0.05$). Despite this, subjects reported that the symptoms they had became worse for a short

period after the end of the 3:1 PPB exposure, from the point at which the pressure was removed from the trousers. This was likely to be due to a large volume of blood flooding into the legs after removal of the supporting pressure. A similar finding has been reported in a previous study, which observed a dramatic drop in blood pressure following removal of a much higher pressure in the trousers than used in this study (6).

Conclusions

These results suggest that the effect of PPB upon aircrew performance should be taken into account when considering altitude protection above 40,000 ft. Further investigation should be conducted to identify the effects of PPB in excess of 45 mmHg, alone, on Tracking performance in isolation.

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