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REVIEW ARTICLE

HYPOXIA AWARENESS TRAINING AND HYPOXIA SIGNATURE: AN APPRAISAL

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Abstract: Hypoxia is an omnipresent threat in high altitude flying and considered the number one physiological problem in aviation. The Hypoxia incident is at its minimum in last one century since heavier than air flying began in 1903. This could be possible because of improved and robust oxygen system design over the last century and Hypoxia Awareness Training which an aviator receives throughout his career. Acute exposure to hypoxia leads to manifestation of various Psychomotor and Cognitive signs and symptoms which vary from person to person. However, this constellation of symptoms does not vary in the same individual on repeated exposure to acute hypoxia. This has been termed as Hypoxia Signature which forms the basis of Hypoxia Awareness Training among aircrew. Various studies have concluded that Hypoxia Awareness Training results in early identification of in-flight hypoxia leading to corrective action on time and prevention of catastrophic events in the air. Hypobaric Chamber Training has traditionally been the mainstay for hypoxia awareness training. However, various other modalities like Reduced Oxygen Breathing Device (ROBD) and Combined Altitude and Oxygen Depleted (CADO) paradigm are also being used to impart Hypoxia Awareness Training. In this article, author has reviewed need for Hypoxia Awareness Training (HAT), rationale behind such training along with various methods being employed currently in IAF and

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world over. The article also discusses objective evidence of effectiveness of HAT and its need to be extended to commercial and general aviation to prevent avoidable loss of lives, property and precious resources due to hypoxia.

Keywords: Hypoxia, Hypoxia Signature, Hypoxia Awareness Training, Hypobaric, Normobaric, ROBD

INTRODUCTION

Hypoxia is one of the most significant omnipresent physiological threats in aviation. Human body is extremely sensitive to Oxygen deprivation which start affecting at as low altitude as 5000 ft where night vision deteriorates. Hypoxic Hypoxia is the most commonly encountered type of hypoxia in aviation where there is a reduction in Oxygen tension in the arterial and capillary blood due to low Oxygen tension of the inspired gas (PIO_2) associated with exposure to altitude [4]. However, other types of hypoxia may be encountered in aviation as well e.g. Anaemic Hypoxia due to Carbon Monoxide poisoning and the Ischaemic Hypoxia due to exposure to low temperature at altitudes and circulatory shunting produced by effects of sustained acceleration. Hypoxia was recognized as a problem in ascent by Paul Bert and he scientifically studied the effect and ways to counter it. The miscalculation in Oxygen requirement by Sivel, Croce-Spinelli and Tissandier proved fatal for Sivel and Croce-Spinelli and they became the first documented victim of hypoxia on ascent. Hypoxia has been taking lives throughout the last one century of aviation since wright brothers paved the way to heavier than air flying in 1903. Even today, USAF and US Navy is battling with the Unexplained Physiological Events (UPEs)-likely to be hypoxia where they had to ground more than two dozens of A -10 Thunderbolts, F-35A Lightnings and T-6A Training Aircraft in 2017 [6]. As recent as in Jun 2017, US Navy lost their four FA-18 Pilots due to hypoxia. The relative incidence of various causes of hypoxia inflight over 14 year period in a large military air force concluded that failure of oxygen regulator and pressurization were main factors in a number of aircraft incidents and losses [3]. Despite these incidences, the fact remains that Hypoxia related incidents have dropped significantly due to improved Oxygen system designs and Hypoxia Awareness Training that Aircrew receive throughout their career [4]. One estimate suggest that such events are even lesser than one percent per annum which is considered acceptable risk in Aviation [5]. However, this should not result into a false sense of security against prevention strategy of hypoxia. Hypoxia is likely to remain a threat in high altitude flying especially in general aviation and commercial aviation. Most of the regulator does not mandate the physiological training of the aircrew in these sectors making them more vulnerable. The subtle nature of hypoxia symptoms (table 1 and table 2) makes it difficult for an inexperienced aircrew (who is unaware of his hypoxia signature) to identify it well on time. The importance of physiological training for identifying hypoxia and taking actions to counter its effects well on time cannot be overemphasized. Acute exposure to hypoxia can quickly incapacitate an unsuspecting pilot who may commit errors of omission and commission leading to devastating outcomes. It is possible that role of hypoxia could not be established in significant no of fatal aviation accidents due to the nature of its manifestation.

Acute Exposure to Hypoxia

Tab. 1. Early covert symptoms during acute exposure to Hypobaric Hypoxia [4].

S No	Covert Symptoms
1	***Visual Functions***
(a)	Perceived Reduced Light Intensity
(b)	Visual Acuity diminished in poor illumination
(c)	Increased Light Threshold
(d)	Narrowed Peripheral Vision
2	***Psychomotor Functions***
(a)	Impaired Learning of Novel Task
(b)	Impaired Choice Reaction Time
(c)	Impaired Eye-Hand Co-ordination
3	***Cognitive Functions***
(a)	Impaired Memory

Tab. 2. Overt symptoms due to exposure to acute Hypobaric Hypoxia [4].

S No	Overt Symptoms
1	Personality Change
2	Lack of Insight
3	Loss of Judgement
4	Loss of self-criticism
5	Euphoria
6	Loss of Memory
7	Mental Incoordination
8	Muscular Incoordination
9	Sensory Loss
10	Cyanosis
11	Hyperventilation and its symptoms
(a)	Dizziness
(b)	Light Headedness
(c)	Feelings of Unreality
(d)	Feelings of Apprehension
(e)	Neuromuscular Irritability
(f)	Paraesthesia of Face and Extremities
(g)	Carpopedal Spasm
12	Semi-consciousness
13	Loss of Consciousness (LoC)
14	Death

Hypoxia Signature

It was observed that individuals who had exposure to hypoxia in the past were more likely to recognize it on subsequent exposures. Acute exposure to hypoxia leads to manifestation of various Psychomotor and Cognitive signs and symptoms which vary from person to person. However, this constellation of symptoms does not vary in the same individual on repeated exposure to acute hypoxia [4]. AM Smith compared this peculiarity of individual responses to hypoxic exposure to their signature and termed this observation as 'Hypoxia Signature' [12]. He proposed that symptoms experienced by hypoxic subjects are individualized and follow the same pattern on repeated exposures which allow the individual to recognize it early on subsequent exposures. This feature of manifestation of hypoxia is the basis for 'Hypoxia Awareness Training' world over. Further, it was also observed that the past exposure to hypoxia also improved the Time of Useful Consciousness (TUC). These beneficial outcomes of past experience of exposure has been utilized world over as 'Hypoxia Awareness Training' (HAT) as a part of Hypoxia Prevention Program (HPP) where aviators are allowed to experience hypoxia under controlled environment to recognize their hypoxia signature.

Hypoxia Prevention Program (HPP)

Hypoxia does not cause pain or discomfort so its onset can be insidious due to which it can remain unidentified by its victim who are not aware of its dangers resulting in accident and fatalities among aviators. Hypoxia Prevention Program (HPP) aim to reduce the incidences of hypoxia inflight by providing physiological equivalent altitude to the aviator during high altitude flying by supplementing the available oxygen (increasing concentration of oxygen in the breathing air corresponding to changing ambient pressure (raising FIO_2 corresponding to changing ambient P_B) or by increasing the pressure of the cabin (raising P_B inside the cockpit and keeping FIO_2 constant at 21% by breathing normal air). Recognizing Hypoxia on time so that corrective actions can be taken with in the 'Time of Useful Consciousness (TUC) or Effective Performance Time (EPT)' is integral part of any HPP. This is incorporated into Hypoxia Awareness Training (HAT). The TUC or EPT is defined as the interval that elapses between a reduction in oxygen tension of the inspired gas and the point at which there is a specified degree of impairment of performance. Practically, it is considered as the period during which the affected individual retains the ability to act appropriately to correct his or her predicament. Researches usually define it as the interval that elapses between a reduction in oxygen tension of the inspired gas and the point at which there is at least two consecutive errors in the Cognitive Function Test prescribed to the individual [4]. It is noteworthy that the TUC at a given altitude is shorter when hypoxia is induced by Rapid Decompression rather than by slow ascent. It is influenced by many factors, most important ones are:

1. Pulmonary Ventilatory Response to Hypoxia
2. General Physical Fitness
3. Age
4. Degree of training
5. Previous Experience of Hypoxia
6. Physical Activity/ Exercise
7. Extremes of Temperature
8. Hyperventilation

HPP consist of didactics on hypoxia and its physiological effects along with training of aviators on how to use the oxygen system of the aircraft properly and effectively by demonstrating how to use mask and test the oxygen system before every sortie. 'PRICE' check is a useful acronym to check the oxygen system where '**P**' stands for Pressure which means that aviator should ensure that there is enough pressure and quantity of the oxygen to complete the flight, '**R**' stands for Regulator which means that aviator should inspect the oxygen regulator for its proper functioning and if continuous flow system is being used, it should be ensured that outlet assembly and plug-in coupling are compatible. 'I' stands for Indicator which means that oxygen flow indicator which is located either on the oxygen regulator or within the oxygen delivery tube should show steady flow on donning the mask and breathing through it. 'C' stands for Connections which means that aviator should ensure that all connections like oxygen lines, plug-in coupling and the mask are secured and intact. 'E' stands for Emergency which means that the aviator should have oxygen equipment in the aircraft ready for use for those emergencies that require oxygen (Hypoxia, Decompression Sickness (DCS), smoke and fumes and Rapid Decompression) and he should also brief passengers onboard about how to act when such emergency strikes eg location of oxygen equipment and its use.

HPP has been used to train aviator by most of the professional Armed Forces of the world. Traditionally, practical demonstration of hypoxia has been done using Explosive Decompression Chambers (EDC) or also known as Hypobaric Chamber or Altitude Chamber which reduces pressure inside the chamber by sucking out air resulting in reduced pressure inside the chamber to simulate hypoxia during ascents and descents (the pressure changes are kept similar to the rates of ascents and descents in the aircraft). The aviator experiences hypoxia by removing the oxygen mask at the specified altitude in the EDC (mask-off hypoxia) where he/ she is asked to perform simple cognitive tasks (eg simple mathematical test like subtraction/ multiplication or division) and keep writing their signature to demonstrate effect of hypoxia on hand-eye co-ordination and mental functions. They are also demonstrated effect of hypoxia on visual acuity (using modified 'snellen's chart') and colour perception (colour vision chart). The moment aviator commit two errors in the cognitive test he is asked to correct hypoxia by donning the mask and switching over to 100% oxygen. SpO_2 (Blood Oxygen Saturation) is monitored during this process and most of the institutions do not allow it to fall below 85% as serious complications are likely to manifest below this level. However, high cost, risk of Decompression Sickness (DCS), Barotrauma and Loss of Consciousness associated with hypobaric chamber training has forced most of the aeromedical training centers in the world to think of alternative methods to provide effective simulation of hypoxia on ground [1,9].

HAT through Reduced Oxygen Breathing Device (ROBD) has emerged as an alternative to EDC which is portable, light-weight, cost effective and easy to use and maintain. It can be useful in remotely located bases, without the need for the aircrew to report to aeromedical training centers. Aircrew can complete HAT and return to their respective squadrons same day, saving time and cost. HAT through ROBD is more close to operational scenario of in-flight hypoxia where aircrew gets signs and symptoms of hypoxia while wearing the mask (Mask-on Training) as against EDC training where aircrew gets it on doffing the mask. In addition, in ROBD, the instructor can participate in more runs, without risking re-exposures to high altitude (DCS). This allows efficiency gains for the training organization [9,13]. Gradually, world has moved towards HAT through ROBD. Presently, IAF is using ROBD to provide HAT after Kumar A et al demonstrated that Normobaric Hypoxia is an effective and useful tool for HAT which can be employed in the IAF, especially in fields [9]. However, HAT through ROBD doesn't demonstrate dysbarism (effect due to pressure changes viz ear clearance, GI symptoms due to expansion of gases and RD).

This limitation of HAT through ROBD has been attempted to circumvent by combining HAT using EDC and ROBD both which was named as Combined Altitude and Depleted Oxygen (CADO) paradigm where aviator breathes mixed gas containing Oxygen (10%) and Nitrogen (90%) at 10,000 ft inside EDC. CADO is theoretically safer than traditional training at a simulated altitude of 25,000 ft (7620 m) due to a much lower risk of decompression sickness (DCS) and has greater fidelity of training for fast jet aircrew (mask-on hypoxia) [11]. However, this has not gained much popularity as it retains the inherent disadvantage of high cost of maintaining EDC.

Hypoxia Prevention Programme has been given due importance by military aviation. HPP is provided periodically to all military aviators every three or five years. IAF conducts refresher HAT every three year for its pilots. However, civil aviation has shown apathy towards it. Though ICAO advises HPP as a safety measures but it is not mandatory for a commercial airline. Few commercial airlines are providing HAT to their pilots. Situation is even worse for general aviation where there is no HPP is in place. Most of the general aviation pilots are not undergoing any aeromedical training including HAT. No wonder majority of hypoxia related incidences are reported from this neglected and unorganized segment of aviation. It is high time that periodic aeromedical training be made mandatory and linked to their requirement for renewal of pilot license for all categories of pilots.

Effectiveness of Hypoxia Awareness Training

Anecdotal evidence of effectiveness of HAT is plenty which has allowed this form of training to survive this long since its inception despite close scrutiny and various reported complications of Loss of consciousness (LoC), DCS and Barotrauma. However, various studies also provided objective proof of its effectiveness in military aviation. The U.S. Air Force showed that 80% of pilots who had not received previous training required up to 15 secs to don their oxygen masks [10]. Island and Farley analysed incidence of hypoxia in USAF over 14 years (1976 to 1990) and reported that only 3.8 % of trained aircrew who had undergone HAT experienced LoC in comparison to 94% of untrained passengers. They attributed this to effectiveness of HAT among trained aircrew [7]. Analysis of hypoxia incidence in Australian Defence Force over 11 years (1990 to 2001) revealed that among all aircrew who had undergone HAT, 76% of cases self-recognized it, 10% were recognized by another trained crew members and only 14% remained unrecognized, establishing the effectiveness of HAT [2]. Smith demonstrated that the pattern of symptoms reported after acute hypoxia was similar to the symptoms recalled from previous exposure during HAT three years back suggesting that individuals hypoxia signature remained stable over a period of three years [12]. Johnston et al demonstrated that recall of hypoxia symptoms may remain stable for upto six years [8]. Yoneda et al found that older military aircrew responded faster during TUC on exposure to acute hypoxia (reduced tolerance to hypoxia) which he attributed to previous exposure to hypoxia during HAT [14].

Hypoxia Prevention Programme in IAF

EDC till recently has been mainstay of Hypoxia Prevention Programme in IAF. However, due to restricted serviceability of its EDC, ROBD is being used for HAT. HAT is provided by breathing 7.7 % of oxygen mix air through a mask connected to ROBD (breathing FIO_2 of 7.7% at 3000 ft, location of Institute of Aerospace Medicine IAF where this training is given, is equivalent to 25,000 ft of lung altitude) for 5 min. The participants lists out all the hypoxia symptoms experienced during this period while performing cognitive test in the form of Mathematical Processing Test and continuously writing his signature in a piece of paper [9]. This allow them to recognize their Hypoxia Signature in a safe and controlled environment which is close to their operational setting where they are likely to get hypoxic while wearing mask (Mask-on hypoxia). As per Standard Operating Procedure (SOP) of hypoxia, when the aviator has a slightest doubt of getting hypoxia, he/ she switches over to 100% oxygen immediately and descends to below 10,000 ft after announcing on RT. This HAT through ROBD is fast and safe and has been acceptable to the clientele [9]. HAT is given as a part of five days Operational Training in Aerospace Medicine (OPTRAM) course for the fighter pilots of IAF at IAM IAF (Bangalore) and for transport and helicopter pilots at No 1 and No 2 Aeromedical Training Centres (AMTCs) located in Hindon and Hyderabad respectively. Paratroopers and Special Forces of Indian Army (IA) also undergo HAT at IAM IAF routinely. Presently, OPTRAM is linked to the Instrument Rating of the pilot. Hence, all IAF pilots undergo HAT and OPTRAM course at least once in every three years (refresher).

CONCLUSION

Despite the reducing incidence of hypoxia in military and commercial aviation, threat of hypoxia in high altitude flying remains and cannot be overlooked. HAT is an effective way to address this issue. Majority of hypoxia related incidents could be identified and corrective actions can be taken on time due to HAT, thus, averting any loss of life and property. All pilots including General Aviation should undergo HAT and this should be linked as a requirement for renewal of pilot license. This will prevent avoidable loss of lives, properties and expensive resources due to hypoxia.

AUTHORS' DECLARATION:

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