**Annotated Reference List**

Billings, C.E. (1974). Evaluation of performance using the Gedye task. *Aerospace Medicine, 45* (2), 158-131. Billings has created a complex psychomotor task to examine early states of decreasing consciousness and performance at sea level, 8,000 feet followed with decompressions to some higher altitudes with and without use of oxygen. The Gedye task tested recent memory and reaction time for 5 subjects while learning and reproducing a proper sequence using three key switches and three lights. Learning curves creating a baseline for both, sea level and 8,000 feet were created. Initial learning was shown to be rapid. Breathing oxygen and air at 8,000 feet resulted in increased initial learning. However with increased number of trials the difference in learning curves disappeared creating overall insignificant results between air and oxygen breathing after the initial learning period.

Billings, C.E. & Ernsting, J. (1974). Protection afforded by phased dilution oxygen equipment following rapid decompression: Performance aspects. *Aerospace Medicine, 45*(2), 132-4.

Billings and Ernsting (1974) conducted 96 experiments in which six experienced subjects were exposed to two-seconds decompressions from 8,000 to 35,000, 37,000, 39,000 and 41,000ft. Given four conditions, a phase- dilution mask was used to deliver oxygen before, during, and after the decompression, or oxygen was provided five, ten or fifteen seconds after decompression at the above stated altitudes. Using Gedye light switch cognitive tasks, the research showed that the performance was significantly distorted (p<0.01) in four cases; the decompressions to 37,000 and 39,000 ft with a 15 seconds delay of oxygen delivery and decompressions to 41,000 feet with 10- or 15-seconnds delay in oxygen delivery. The authors suggest that during unexpected decompression the emergency recognition rapidity and breathing pattern determine how fast the subject will don his/her mask. This research strengthens previous research by finding that only a small fraction of subjects will don a mask within 5 seconds upon unexpected decompression.

Bryan, C.A. & Leach, W.G. (1960) Physiologic effects of cabin pressure failure in high altitude passenger aircraft. *Aerospace Medicine,* 31, 267-75.

The researchers reviewed the physiological hazards of cabin depressurization during rapid decompression resulting in hypoxia. The research has been based on Canadair calculation that CC106 aircraft can decompress from 8,000 to 40,000 feet in 2.5 seconds. They further define TUC depending upon barometric pressure and method of exposure (e.g. mask removal or rapid decompression), inhaled gas mixture prior exposure and methods of measuring TUC. The subjects were decompressed from 8,000 feet to 40,000 feet in 2.5 seconds. Different aviation masks were used and their weak seal created a problem with proper oxygen delivery. Also, the subjects exposed to hypoxia ended up dropping the masks. The established endpoints were an inability to turn-off an alternating light and disturbance measures on EEG. Average TUC of exposure to 40,000 in 2.5 seconds was 18 seconds. The research concludes that in order to maintain continuous consciousness 7 seconds create the endpoint for donning a mask.

Donaldson, R.T., Carter, E.T., Billings, C.E., Hitchcock, F.A. (1960). Acute hypoxia during rapid decompression and emergency descent in a commercial aircraft. *Aerospace Medicine,* 31, 842-51.

Oxygen saturation and TUC in a rapid decompression model causing acute hypoxia were explored in the hypobaric chamber simulating a rapid decompression of a B707. The simulation consisted of decompression from 41,000 ft (8.500 ft cabin altitude) to 36,000 ft in 30 seconds followed seconds followed by an descent to 14,000 ft. An ear oximeter was used to collect the data from four subjects. (Oximeter had an established error of 8% in 50 to 70% of SpO2.) The endpoint for TUC was determined by inability or making mistakes when writing down numbers counting backwards from 100. The scenarios conducted were 1/ no oxygen given until reaching an endpoint, 2/oxygen given with no delay, 3/15 seconds and 4/ 30 seconds upon reaching 14,000ft cabin altitude. After decompression with no oxygen given, the SpO2 increased from 90% at 8,500ft to a range of 76.8% to 87.1% in 15 seconds at 27, 000ft. The SpO2 range of 50.3% to 74.4% in 30 seconds happened at 36,000ft. The average TUC was 32 seconds for all 4 subjects. Further, the article gave SpO2 levels and TUC for the remaining 3 conditions. The authors concluded that during rapid decompression SpO2 is about 70% and suggest taking oxygen within 15 seconds to avoid TUC.

Ernsting, J. (1978). Prevention of hypoxia-acceptable compromises. *Aviation Space and Environmental Medicine. 49* (3), 495-502.

Ernsting (1978) conducted a literature review in which he reviewed the studies on mild and rapid decompression hypoxia. The trade-off between passengers’ and aircrew comfort and aircraft design denotes the allowable level of hypoxia. Although the ideal cabin altitude was found to be 5,000 to 6,000 feet, research and practical experience concluded that is safe for aviators to operate without supplemental oxygen up to 12,000 feet. The initial learning phase of a complex orientation task at 5,000 or 8,000 feet or serial problem solving and vigilance at 12,000 feet were affected by mild hypoxia. There was no performance decrease after the tasks were practiced. Ernsting concludes that the use of no supplemental oxygen for aircrew operating at 8,000 feet should not be accepted because of significant impaired ability to react properly to unexpected emergency. Reviewing the rapid decompression effects, the author further concludes that the minimum acceptable alveolar oxygen tension on rapid decompression is 30 mm Hg.

Humphreys, S., Deyermond, R., Bali, I., Stevenson, M, Fee, J.P.H. (2005). The effect of high altitude commercial air travel on oxygen saturation. *Anaesthesia,* 60, 458-460.

This research tackled the hypoxia high-altitude problem studying SpO2 and heart rate levels in commercial aircraft flights. Using a pulse oximeter, eighty-four subjects of age 1 to 78 years flew short and long-haul flights using ten different airlines flying in maximum altitudes of 37,000 to 41,000ft. Both, short and long-haul flight yield similar results: SpO2 decreased from 97% at from ground level to 93% at altitude which resulted in a statistically significant difference (p<0.05) (Humphreys, Deyermond, Bali, Stevenson, Fee, 2005). 54% of subjects had SpO2 of 94% or less (Humphreys et al, 2005). The heart rate levels did not show a statistically significant change (on average 82 bpm to 80 at altitude). This study suggested that hypoxia combined with low humidity, dehydration and immobility may be a factor in death rate during and after the flights considering the potential additional health problems of passengers.

Izraeli, S., Avgar, D Glikson, M. Shochat I, Glovinsky, Y., Ribak, J. (1988) Determination of the “time and useful consciousness” (TUC) in repeated exposures to simulated altitude of 25,000ft (&, 620m). *Aviation Space Environmental Medicine.* 59, 1103-5.

The authors conducted a safe, simple and objective research to establish a more precise method for Time of Useful Consciousness (TUC) determination. During a regular training 18 healthy pilot subjects were exposed to 25,000 feet 8 months prior to two consecutive exposures to the same altitude in a commercial altitude chamber. A measure of attentive function test (adding pairs of 2-digit numbers) had 16 pages with 20 exercises on each page and they had to turn the page every 30 seconds. The endpoints of TUC were determined by two mistakes in addition or by inability to perform the task. The fact that 5 subjects never reached their endpoints created unwanted end- points. For determination of TUC. (480 seconds were denoted as the safety limit). Some subjects were trembling and incapable to respond (denoted endpoint) yet not making any addition’s mistakes. The medians of TUC were 267.5 seconds in first exposure and 240 seconds in the second one. Even though more subjects during the second exposure reached the safety TUC’s limit, the difference between exposures was not statistically significant. The minimal capabilities required from the pilots in this emergency situation should be analyzed and the test should be validated by repeated exposures of large number of individuals to simulated high altitudes to clarify the meaning of TUC.

Kelly, P.T., Swanney, M.P., Frampton, C., Seccombe , L.M., Peters, M.J. & Beckert L.E. (2006). Normobaric hypoxia inhalation test vs. response to airline flight in healthy passengers. *Aviation Space and Environmental Medicine. 77,* 1143-7.

The authors have conducted a study that 1/ determined the levels of desaturation using healthy subjects during Normobaric Hypoxia Inhalation Test (NHIT desaturations and 2/ validated NHIT. The NHIT test based upon the Aerospace Medical Association(ASMA)’s recommendation involves breathing 15% oxygen in a nitrogen balance at sea level for 20 minutes. A subject’s arterial oxygen tension less than 55 mmHg would result in a need to use oxygen in flight. The NHIT has shown similar and significant desaturations (SpO2); there was no significant difference between NHIT’s SpO2 and in-flight SpO2. There was a significant difference between the lowest NHIT’s SpO2 (90 +/-2%) and in-flight SpO2 (88+/-2%). The authors concluded that commercial travel decreases oxygen saturation levels significantly (97% to 92% of SpO2) and NHIT can be used to determine oxygen need for subjects.

Lee, A.P. & Yamamoto, L.G. (2002) . Commercial airline travel decreases oxygen saturation in children. *Pediatric Emergency Care,* 18 (2), 78-80.

Eighty healthy children of age 6 months to 14 years were subjects and were tested for hypoxia on pacific flights by determining SpO2 and heart rate changes. Measurements were collected 3 and 7 hours into the flight using an oximeter. The average SpO2 decreased from 98.5% to 95.7% in 3 hours and to 94.4% 7 hours into the flight, creating statistical significance (p<0.001). Average heart rate increased from 100 to 105 bpm in 3 hours and to 108 in 7 hours into the flight. Statistically significant results were obtained comparing heart rate and oxygen saturation (p= 0.01 & p, 0.001, respectively). (Lee & Yamamoto, 2002 ). While children between 6 months to 6 years had increases in SpO2, children younger than 2 years didn’t have a heart rate increase. Oxygen saturation and heart rate were affected significantly more during sleep. (p=0.002 and p=0.043 for SpO2 in sleep in 3 hours and 7 hours, respectively. p= 0.012 for heart rate in sleep in 7 hours into the flight). Cabin altitude was 6,760 ft. The authors mentioned an additional worsening effect of fatigue and jet-lag, compounding the effect of hypoxia. The research concludes that rather than acclimation of oxygenation SpO2 levels continued decreasing with increased travel time.

Luft, U.C. & Noell, W. (1956). Manifestations of brief instantaneous anoxia in man. *Journal of Applied Physiology,* 8 (4), 444-454.

Anoxia, extreme form of hypoxia was tested in 6 to 18 second exposures to 68-70 mmHg (about 53,500ft) while breathing oxygen in two subjects to determine the sequence of cerebral events. TUC between 50 to 70 mmHg was previously determined as 15 seconds. (Luft & Noell, 1956). Neurological changes and electroencephalographic effects were studied. Fast neurological events were observed 1/ state of automatism, 2/arrest and 3/losing posture with a head fall. During the automatism phase (13 to 15 seconds after decompression at 70mmHg) confusion, loss of comprehension and amnesia occurred. Electroencephalogram (EEG) deviated only slightly from a normal pattern. Lasting about 8 seconds, the arrest phase occurred 17-19 seconds upon rapid decompression with sudden loss of consciousness. Fixation of the eyes, staring, rolling eyeballs while posture and respiration is maintained was observed. EEG showed continuous increase in slow wave pattern. Lasting 12 seconds, head fall resulting in overall postural failure happened 20 seconds after decompression. Brain inactivity is portrayed on EEG. The authors compared this experience to epileptic seizures. The research concludes the loss of consciousness occurred at 7 to 8 seconds after exposure.

O’Connor, W.F., Scow, J., Pendergrass, G. (1966). Hypoxia and performance decrement. Federal Aviation Agency Office of Aviation Medicine, AM 66- 15.

The authors conducted a research in which they attempted to create a more descriptive concept of TUC other than time at which purposeful acts can still be performed (O’Connor, Scow, Pendergrass, 1966). The performance index was defined as a ratio of task units completed in hypobaric conditions to tasks units completed in normobaric conditions. (O’Connor et al, 1966). In order to simulate a complex aviation task, a serial reaction complex coordinator machine was used. The performance task consisted of matching stimulus lights with response lights. 45 lights organized in 4 quadrants, 20 stimulus, 20 response and 5 control lights were organized in 4 quadrants. In the first series at 35,000 ft a straight match problem requiring matching stimuli with response lights was used. In the second series at 27,000 ft a logic method utilized the remaining 5 control lights as follows:1/ if a white light in each quadrant turned on the correct response was one light below the stimulus light., 2/ if central green light came on the correct response was one light above the stimulus light and 3/ if both white lights and green light came on the correct response was a straight matching light. The results were 1/ performance deterioration by 2.12 minutes comparing completion on oxygen versus no oxygen with the performance baseline at 35,000. 2/ average performance rate was 65% of normal work rate at 0.8 minute and zero at 1.35 minutes at 35,000 ft. 4/ average performance rate was 90% of normal work rate at 0.8 minute, 50% at 1.4 minutes and 0 at 3.4 minutes at 27,000 ft, respectively. Performance deterioration rate after 24 seconds of 10% for each 6 seconds at 35,000ft and 5% for each 0.7 minute was observed. The data suggested that quantified indexes of operator capability follow the blood-oxygen saturation curves – a correlation that is severely attenuated when employing the dichotomous TUC concept (O’Connor et al, 1966).

Truszcznski, O., Wojtkowiak, M., Biernacki, M., Kowalczuk, K. (2009). The effect of hypoxia on the critical flicker fusion threshold in pilots. *International Journal of Occupational Medicine and Environmental Health*, 22 (1), 13-18.

This research examines 1/ how the ability to perceive light is affected by hypoxia using the Critical Flicker Fusion threshold (CFF) and 2/ what are the relationships between the visual perception versus blood oxygen saturation (SaO2) and Heart Rate (HR). The subject were 14 active-duty pilots that were first examined in hypobaric chamber at 5,000 meters without oxygen and then they were trained to used device for CFF measurement. The measurements took place at normobaric, initial and final phases of hypoxia. The hypoxic environment of 5,000 meters resulted in 1/ significant decrease of CFF, F(3.39)= 3.207, p < 0.05, 2/ in significant decrease of SaO2, F (3.39) = 52.651, p< 0.001, 3/ in significant HR increase F(3.39) = 7.356, p <0.001. Further, there was no significant relationship between CFF, SaO2 and HR. Correlation test revealed that the greater the decrease in SaO2 and the greater the increase of HR, the greater the decrease in CFF threshold in the hypoxic environment.

Ulrich, C. & Luft, M.D. (1961) Altitude Sickness. Aviation Medicine: 120-142.

The authors discussed altitude sickness, hypoxia and hypocapnia, slow and rapid decompression, pathology and post-mortem findings. Emphasizing the importance of slow ascent hypoxic research, they divided the altitude dependent subjective and objective hypoxic symptom onset into four phases. 1/ Indifferent (up to 10,000ft), 2/ Compensatory (10,000 to 15,000ft), 3/ Distress (15 to 20,000ft) and critical (20 to 25,000ft).

Ascending about 1000ft per minute, air hunger (an additional breath) is accompanied with restlessness, slight headache and dizziness are experienced between 10 to 12,000ft. Visual tunneling and auditory function slow decay occurs. A considerable amount of flying performed from 10,000 to 15,000 results in light headedness, like hangover feeling but without any consequences. Respiratory effects with little or no variation of breath per minute happen at 5 to 10,000ft and they further increase with altitude. Breathing becomes irregular at altitude and respiratory failure means irreversible damage to respiratory centers in the brain. Heart rate increases with increase of respiration, pulse rate increases constantly but not higher than 30 to 40 bpm above sea level value. More blood flows to the brain and heart. Most healthy subjects experience no circulatory problem even close to unconsciousness. Other may be subjects to an exception; cold sweat, nausea and fainting symptoms caused by CNS dysfunction further affecting the cardiovascular system may happen much earlier. Unlike for high altitude inhabitants (altitudes above 10,000ft), gradual ascent to altitude has shown no extra red cells or higher level of hemoglobin. Dark adaptation is distorted at 6 to 7,000ft followed by loss of light perception and contrast at 15,000ft. High frequency sound sensitivity? is lost with altitude; at 18 to 20,000 ft only medium to low frequency sound can be perceived. Touch and pain is exaggerated up to 15,000 ft and becomes dull above. Clumsiness and uncoordination happens up to 16,000 ft resulting in hyperflexia up to 24,000ft. Psychological changes occur above 12,000 ft (decreased short-term memory, above 14,000 mental fatigue, lethargy, sleepiness, euphoria). Above 18,000 ft attention fluctuates with a loss of memory, muscle control, attention narrowing and sound judgment is lost. Above 20,000 ft to unconsciousness, symptoms are; loss of sensory and motor responses, twitching, loss of time perception, laughter, anger and willingness to go on.

Finally, this research used an hypobaric chamber to assess altitude tolerance of 100 healthy men in a slow ascent model creating a critical threshold in altitudes between 16, 000 and 30,000 ft. The denoted endpoints were inability to write and comprehend. The critical threshold showed to be the highest (55%) at 23,000ft, the second highest (20%) at 26,000ft and the lowest (3%) at 16,000ft.