Hypoxia: An Analysis of Hypobaric Chamber Training

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved April 2019 by the
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ARIZONA STATE UNIVERSITY

May 2019

ABSTRACT

Hypoxic hypoxia is a physiological condition which can manifest as a result of reduced barometric pressure, resulting in an insufficient amount of oxygen for use by the tissues in the body. Hypoxic hypoxia is of concern to pilots due to dangerous impairment the condition can cause in-flight, such as short term memory loss, incoordination, or incapacitation. Several aircraft incidents and accidents have been attributed to hypoxia in the past ten years. To train for hypoxia recognition, high altitude chambers are used to induce hypoxia in participants, through a reduction of pressure inside a reinforced chamber. The training allows participants to experience their personal physiological symptoms of hypoxia in a controlled environment, in order to be trained in recognition and intervention techniques. This study surveyed 110 participants of high altitude chamber training to analyze perceptions, experience, and attitudes of respondents toward the training. Significant results were found; to include 99% of participants stating they would recommend the training to others, and 96.8% stating they felt they were a safer pilot, crewmember, or other support personnel due to attending high altitude chamber training. Two questions related to formal regulatory oversight revealed non-significant results. The purpose and results of this study are intended to support the improvement of aviation physiological training practices, in an effort to reduce hypoxia-related aircraft incidents an accidents in the future.

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CHAPTER 1

Introduction

Statement of the Problem

The aviation industry approaches safety from a proactive stance (Stolzer & Goglia, 2015). The safety of pilots and passengers are the priority in any aircraft operation. However, several general aviation accidents and incidents have been attributed to hypoxia in the past decade. In many cases, lives were lost or put into jeopardy.

Voluntary reports from general aviation pilots contributing to the Aviation Safety Reporting System (ASRS) database indicate that hypoxia events are continuing to occur. These accidents and incidents range in severity and resulting outcome. The resulting indication is that re-evaluated, additional, or improved physiological training for pilots may be warranted in an effort to reduce the number of hypoxia related incidents and accidents which occur.

One form of physiological education, high altitude chamber training (HCT), is an available resource to contribute to the proactive approach to safety. Due to the unique ability for participants to experience hypoxia in a controlled environment in HCT, the aviation industry may benefit as a result through improved hypoxia training and awareness, which could lead to the reduction of hypoxia-related incidents and accidents. Research must be done to understand whether HCT provides greater knowledge and experience to pilots in recognizing their symptoms of hypoxia, and whether the participants of HCT view the experience as one that improves safety in the cockpit. Such analysis may provide support for greater use and emphasis on the importance of pilots completing HCT.

Background

The physiological limitations of the human body have direct impact on flight operations, and the training and precautions necessary for safe flight. Of physiological concern to aviators is becoming hypoxic due to increased altitude and subsequent reduction of barometric pressure experienced during flight (termed hypoxic hypoxia) (Neuhaus & Hinkelbein, 2014). Hypoxia is an inadequate supply of oxygen reaching the tissues in the body. Symptoms and tolerance of hypoxia vary between individuals; however, common symptoms of hypoxic hypoxia include headache, tingling, cyanosis, vision impairment, personality changes, and numerous forms of other cognitive impairment (Neuhaus & Hinkelbein, 2014). Due to the complex environment and tasking associated with piloting an aircraft, impairment in any form can lead to operational problems, or inability to respond appropriately to both normal and abnormal situations.

General aviation encompasses all civil aircraft flown outside of airline and military operations (Dillingham, 2001). Hypoxia is often perceived amongst the general aviation population as a condition which is primarily associated with high altitude flying. This perception leads to the belief that hypoxia is most often a non-issue at common altitudes operated at by general aviation pilots (for example, 8,000-14,000 feet). However, research indicates that hypoxia and accompanying physical and cognitive impairment can present at altitudes as low as 5,000 feet at night (Harding, 1999), and 8,000 feet in daytime operations (Petrassi, Gaydos, Ramiccio, & Walters, 2011). Training in the recognition of symptoms and efficient operation of oxygen systems is paramount to a safe and positive outcome in hypoxia scenarios (Cable, 2003).

One form of training available to aviators to become knowledgeable on hypoxia and other related physiological topics is high altitude chamber training (HCT). A high altitude chamber is a reinforced chamber which simulates various altitudes through the associated ambient pressure changes. Participants inside the chamber breathe 100% oxygen until reaching a specified altitude (commonly 25,000 feet), at which time they remove their oxygen mask to induce hypoxia. The purpose of the training is for participants to experience their unique symptoms of hypoxia, to recognize when impairment is appearing, and treat themselves for the condition by following a series of steps which mimic actions that would need to be done if the hypoxic event occurred in-flight (Federal Aviation Administration, 2015). Participants are exposed to extensive physiological academics, followed by the applied training inside the chamber.

Federal Aviation Regulations do not presently require high altitude chamber training for any type of pilot certification, however, more comprehensive physiological training is highly recommended as issued in September 2009 by the Federal Aviation Administration in Advisory Circular 61 107-B. Guidance to prevent hypoxia can be found in regulations pertaining to altitude operational limitations without supplemental oxygen, however, these regulatory guidelines allow pilots to fly up to 14,000 feet without supplemental oxygen for up to 30 minutes. These allowances compared against the results of low-altitude and/or low-grade hypoxia impairment research indicate pilots may be at risk for the development of hypoxia at altitudes which may be legal, but places the aviator at risk (Smith, 2007).

Several accidents attributed to hypoxia incapacitation within general aviation operations have occurred over the past ten years (National Transportation Safety Board, 2013). An ASRS database search with hypoxia as a primary or contributing factor to an incident populates numerous reports in which pilots relay their experience and outcomes due to or in conjunction with hypoxia. A common comment amongst such reports being that pilots realized the danger of their hypoxic state only after recovery and upon reflection of the event (ASRS, 2017).

The prevention of hypoxia related accidents and recovery from in-flight incidents may be directly impacted by applied hypoxia recognition training of pilots. This can be demonstrated through analysis of hypoxia events occurring in military aircrews. In one instance approximately 96% of crewmembers having undergone HCT were able to recognize their symptoms before incapacitation occurred (Cable, 2003). Knowledge and preparedness are key to quick recognition and recovery in the event of an in-flight hypoxia event (Cable & Westerman, 2010). HCT allows participants to experience and practice hypoxia recognition and recovery, while reinforcing knowledge in other areas of aviation physiology. While HCT has been available within the civilian sector of aviation since the 1960s, the importance placed on such training by way of regulatory requirement, industry best practice, or emphasis on applicability amongst the general aviation population has not been apparent.

Research Statement

The purpose of this research is to determine the perspectives of high altitude chamber training participants in regard to hypoxia perceptions, training experience, and attitudes towards hypoxia training requirements. The research aims to address the void identified in current literature surrounding feedback from high altitude chamber training participants as to whether such participants see value (defined as a gained technical skill or greater self-awareness) in the training, and whether they view high altitude chamber training as a practice which improves safety and/or should be required training for all pilots.

The research furthers aims to identify implications for future training and whether changes to regulatory standards for physiology training is supported and/or viewed as necessary by HCT participants, in an effort to improve aviation physiological training practices.

Hypothesis

The hypothesis for this study is participants support the use of high altitude chamber training and its application to the improvement of safety, due to the gained skill of hypoxia recognition.

CHAPTER 2

Literature Review

Hypoxic Hypoxia

The effects of atmospheric pressure are especially important to flight operations, and a paramount consideration in the analysis of physiological effects on the human body. Although the concentration of oxygen in the atmosphere remains constant at 20.95% up to 100,000 feet (Asshauer, 2006), atmospheric pressure reduces dramatically with increasing altitude. At sea level, atmospheric pressure is 101.3 kPa or 14.7lb/in^2 (Rainford, Ernsting, & Gradwell, 2016). At 18,000 feet, the pressure of the atmosphere is approximately half of the atmospheric pressure at sea level (Harding & Mills, 1983), as depicted in Figure 1 Atmospheric Pressure. Without appropriate protection, this reduction of atmospheric pressure can become problematic for aviators due to the onset of symptoms associated with insufficient amounts of oxygen reaching the tissues in the body; termed hypoxic hypoxia.

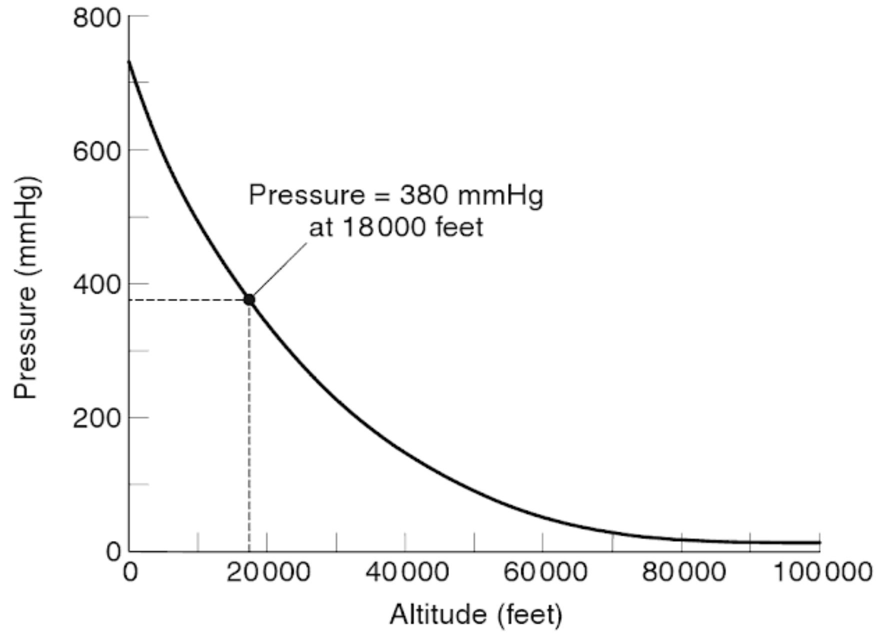

Figure 1 Atmospheric Pressure. Adapted from Arnott, E. J. (2007). *A New Beginning in Sight*. London: Royal Society of Medicine Press.

Hypoxic hypoxia (termed only “hypoxia” in the remainder of the text) is defined as a reduction of oxygen partial pressure in the arterial blood; one cause being the result of reduced atmospheric pressure (Petrassi, Gaydos, Ramiccio, & Walters, 2011). On average, a healthy individual has a blood oxygen saturation (SpO_2) value between 95% to 100%; blood oxygen saturation levels below 90% are an indication of the onset of hypoxia (Acharya, Rajasekar, Shender, Hrebien, & Kam, 2017).

Neural tissue is especially sensitive to hypoxia. In order to maintain normal function, the brain requires a constant and high supply of oxygen; approximately one-fifth of the amount of oxygen inhaled at rest (Nesthus, Rush, and Wreggit, 1997). Hypoxia results in changes to the cardiovascular, respiratory, and central nervous systems (Petrassi et al., 2011). The results of these changes are a multitude of cognitive and psychomotor impairments, in addition to other physical symptoms. This includes increased respiration rate, increased heart rate, tingling of the extremities, light headedness, hot and cold flashes, euphoria, slurred speech, personality changes, lack of judgement, loss of short-term memory, confusion, and incoordination (Harding & Mills, 1983). Effects on auditory sensitivity and perception have also been observed (Ogorodnikova, Pak, Stolyarova, Bogomolova, Korolev, Golubev, & Lesova 2017). Eventual loss of consciousness is assured without sufficient supplemental oxygen or adequate reduction in altitude.

The onset and severity of hypoxia varies based on rate of ascent, altitude, time at altitude, and acclimatization (Petrassi et al., 2011), in addition to individual susceptibility factors such as age and health. Hypoxia is insidious in nature; that is harmful symptoms often begin subtly and may go undetected or may not be recognized until more severe impairments are present. Individuals may not be aware their functions are becoming impaired, recognize personal changes in behavior, or be able to provide self-help in the advanced stages of hypoxia.

The risk and severity of hypoxia increases substantially with increases in altitude. A reference for severity can be found in the analysis of time of useful consciousness (TUC). TUC is the amount of time in which an individual retains enough cognitive and psychomotor abilities to function effectively. For aviators, this translates to the ability to secure their oxygen mask and prepare the aircraft for immediate descent. At 20,000 feet, time of useful consciousness is approximately ten minutes. Comparatively, an individual's time of useful consciousness at 24,000 feet is three minutes, at 30,000 feet is thirty seconds, and at 40,000 feet and above, fifteen seconds or less (see Figure 2 Time of Useful Conciousness.) (Mohler, 2000).

Time of Useful Consciousness (TUC)
By Altitude

Altitude (feet above sea level)	TUC
40,000	15 seconds
35,000	20 seconds
30,000	30 seconds
28,000	1 minute
26,000	2 minutes
24,000	3 minutes
22,000	6 minutes
20,000	10 minutes
15,000	Indefinite

Figure 2 Time of Useful Conciousness. Adapted from Sheffield, P., Heimbach, R. (1996). "Respiratory Physiology." Chapter 5 in *Fundamentals of Aerospace Medicine*, edited by DeHart, R. University of Oklahoma, Oklahoma City, Oklahoma, U.S.: Williams and Wilkins.

Hypoxia Concerns for General Aviation

Most aircraft routinely operating at high altitudes (i.e. commercial airliners) are pressurized to maintain a cabin altitude which is conducive to passenger safety and prevents hypoxia manifestation. While Federal Aviation Regulations (FARs) do not specify a specific altitude requirement for cabin pressurization, industry best practices utilize 8,000 feet as an acceptable cabin pressure altitude (Aerospace Medical Association Civil Aviation Subcommittee, 2008). This best practice is influenced by Title 14 Code of Federal Regulations Part § 91.211, which stipulates the following operational limitations and supplemental oxygen requirements for altitudes above 12,500 MSL:

- Aircraft may not be operated with cabin altitudes above 12,500 feet MSL up to (and including) 14,000 feet MSL unless the minimum flight crew for the aircraft uses supplemental oxygen for any part of the flight which is at the specified altitude for more than 30 minutes

- Aircraft may not be operated with cabin altitudes above 14,000 feet unless the required minimum flight crew uses supplemental oxygen for the duration of flight at the specified altitude
- Aircraft may not be operated with cabin pressure altitudes above 15,000 feet MSL unless all occupants in the aircraft are provided with supplemental oxygen

These regulatory requirements allow a margin of flight up to 12,500 feet MSL without any requirement for supplemental oxygen. While a shift in these regulatory requirements may assist in preventing some occurrences of hypoxia, difficulty in specifying an altitude threshold exists due to wide variability in associated considerations such as geographic conditions, and individual susceptibility factors such as age and health.

For commercial and military aircraft, current regulatory requirements are often a non-issue due to pressurized cabins; the common industry best practice of 8,000 feet is well below altitudes which supplemental oxygen is required (Aerospace Medical Association Civil Aviation Subcommittee, 2008). Hypoxia remains a concern for most commercial airline aircraft primarily for cases of malfunction of pressurization systems and slow or rapid decompression scenarios.

Within the scope of general aviation, many aircraft are not equipped or operated with pressurized cabins. Advancements in aircraft design have produced airplanes with continually increasing abilities to operate at high altitudes, with many of these aircraft readily accessible to the general aviation population (Cable & Westerman, 2010). For example, the Mooney Acclaim with a cruise altitude of 25,000 feet (Grimstead, 2008), the Lancair IV with a cruising altitude of 24,000 feet and optional pressurized cabin (Cable & Westerman, 2010), and the Cessna T206 Turbo Stationair with a service ceiling of 26,000 feet (Cessna, 2017). In most cases, use of a cabin pressurization system is not the norm in these types of aircraft (Cable & Westerman, 2010), leaving occupants the sole option of utilizing supplemental oxygen to prevent hypoxia (Neuhaus & Hinkelbein, 2014).

Despite such aircraft being operated within regulatory confines, operators still face two potential problems. The use of constant flow oxygen systems often has little redundancy and no warning systems to indicate failure (Cable & Westerman, 2010), leading to the possibility of a hypoxia occurrence that may elude the pilot. Secondly, research indicates hypoxia can occur below the 12,500 feet threshold (Nesthus et al.,1997), which may conflict with the regulatory operating allowance of cabin altitudes up to 12,500 feet, and the allowance to fly at altitudes up to 14,000 feet without supplemental oxygen for up to 30 minutes.

The effects of hypoxia have been observed at altitudes as low as 5,000 feet during nighttime operations as observed through degradation of night vision (Harding, 1999), and 8,000 feet during daytime operations (Petrassi et al., 2011). Research indicates that the ability to compensate for hypoxia is reduced and cognitive functioning compromised upon reaching the physiological threshold between 8,000 and 10,000 feet (Nesthus et al, 1997). Across the aviation industry, it is commonly recognized that hypoxia and use of supplemental oxygen is of concern primarily above 10,000 feet mean sea level (MSL) (Pilmanis, Balldin, & Fischer, 2016).

In a study conducted to examine cognitive effects of hypoxia at lower operating altitudes (utilizing 5,000, 8,000, and 12,000 feet), very little decrease in cognitive performance was observed in participants between 5,000 and 8,000 feet (Pilmanis et al., 2016). However, some significant differences were observed between ground level and 12,000 feet, accompanied by a significant difference in the frequency and number of symptoms reported by participants (Pilmanis et al., 2016); these symptoms included reduced coordination, dizziness, light headedness, difficulty concentrating, and sleepiness. Similarly, a significant difference was found in flight performance accuracy between 10,000 feet and 15,000 feet, with significantly lower alertness levels reported between 300 feet and 10,000 feet, and 10,000 feet and 15,000 feet (Steinman, van den Oord, Frings-Dresen, & Sluiter, 2017).

While hypoxia symptom analysis research demonstrates that symptoms of hypoxia increase in severity with altitude (Valdez, 1977), some research has observed hypoxia symptoms at altitudes of approximately 12,000 to 15,000 feet becoming apparent in helicopter crews during periods of activity at altitudes as low as 7,000 feet (Smith, 2007). These measurements were conducted during times of rest (non-tasking of subjects) and during activity (tasking of subjects), to observe effects of hypoxia symptoms in relation to common workload scenarios encountered by aviators. Instances of severe impairment below 10,000 feet remain relatively low, however, research demonstrating the possibility for hypoxic symptoms to become present at lower altitudes than generally anticipated presents a safety concern for general aviation pilots (Smith, 2007).

Another analysis of pilot performance under a mild hypoxic state produced results showing significant differences between an experimental group under hypoxic conditions (breathing reduced oxygen) and a control group under normal conditions (breathing compressed air); when completing tasks during the cruise and descent phases of flight at 10,000 feet and 12,500 feet (Nesthus et al., 1997). A significant difference in observed procedural errors on behalf of the experimental group was noted during the study to occur towards the end of a two-hour session, after the experimental group had been under the induced hypoxic environment for nearly two hours; consistent with the scenario a general aviation pilot may encounter (i.e. flying for a period of time followed by the tasking of descent, approach, and landing) (Nesthus et al., 1997). This study concluded pilots flying at commonly flown altitudes for general aviation operations for greater than two hours should exercise "heightened awareness" for potential errors during the latter phases of flight and prepare for adequate time for descent for physiological recovery (Nesthus et al., 1997).

General Aviation Accidents and Incidents

In October 1999, a Learjet 35 en-route from Florida to Texas was climbing to the assigned altitude when cabin pressurization was lost, resulting in the incapacitation of the Captain, First Officer, and all four passengers (National Transportation Safety Board [NTSB], 2000). The aircraft continued flight on auto-pilot until exhausting all fuel and crashing, with the flight crew never regaining consciousness and perished in the accident. The National Safety Transportation Board ruled probable cause to be incapacitation of the flight crewmembers due to hypoxia following loss of cabin pressurization (NTSB, 2000). This accident is considered to be one of the most defining hypoxia-induced accidents in general aviation history and has been referenced in numerous literature as an example of the dangers of hypoxia.

Despite attempts at greater awareness from the Federal Aviation Administration regarding hypoxia concerns, such accidents and incidents within general aviation operations still continue to occur, as evidenced by NTSB accident reports and ASRS reports. In-flight loss of control due to the pilot's impairment from hypoxia was listed as the probable cause in a Cessna 182 accident in 2012 (NTSB, 2013). After unintelligible responses from the pilot to air traffic control following inquires as to his intentions, the aircraft began an unexplained descent through 11,000 feet and impacted the ground with a right-wing low attitude. Investigators felt that the pilot's vision and judgement should have slowly improved with the descent, however, the rate of descent was likely too rapid for sufficient physiological recovery (NTSB, 2013).

Similar to the 1999 accident, a TMB 900 en-route from New York to Florida in 2014 resulted in the death of the pilot and his passenger when, following signs of cognitive impairment through transmissions with air traffic control, the pilot became unconscious until fuel exhaustion caused the aircraft to crash. NTSB probable cause determined the accident to be a result of a loss of cabin pressurization, followed by incapacitation of the aircraft occupants due to hypoxia (NTSB, 2017). This accident occurred one week after an accident involving a Cirrus SR22, which ran out of fuel and crashed into the Atlantic Ocean, following observation of the pilot being unconscious by intercept fighter jets. Although probable cause could not be conclusively determined due to inability to recover the aircraft and remains, hypoxia was suspected as evidenced by impaired communication with air traffic control and a request to descend for no apparent reason prior to the final radio transmission (NTSB, 2016).

More recently, an erratic flight track and inconsistent communications with air traffic control was found to be indicative of hypoxia in a 2016 crash involving a Beechcraft Bonanza C35. Probable cause was found to be the pilot's decision to fly in instrument meteorological conditions at altitude for longer than 30 minutes, resulting in loss of aircraft control from hypoxia incapacitation (NTSB, 2018).

A search of the Aviation Safety Reporting System database on reports including hypoxia shows numerous occurrences in which accidental errors, misjudgments, and failure to correctly configure aircraft oxygen or other equipment led to a hypoxia related event in-flight. One such report stated a Learjet 25 crew experienced hypoxia in-flight after failing to open the engine bleed valves before takeoff, followed by failure to identify the cabin altitude warning, and failure to don the crew's oxygen masks (Aviation Safety Reporting System [ASRS], 2008a)

A Piper PA-32 pilot reported descending 1,000 feet without clearance while flying under instrument flight rules, after anticipating a lower assigned altitude from air traffic control. While the pilot was monitoring for hypoxia while flying at an altitude of 13,000 feet, the reporting pilot stated they should have requested a lower altitude and acknowledged performance degradation which may have been a factor due to low grade hypoxia (ASRS, 2008b). A similar report was received by a pilot who reported experiencing symptoms of hypoxia while flying into class A and Class D airspace without clearance or contact with air traffic control (ASRS, 2009).

Low grade hypoxia was reported in another incident in which a pilot landed with the landing gear in the retracted position, after flying a three-hour flight with supplemental oxygen but maintaining an SpO_2 of 92% (ASRS, 2010). This incident relates to previous research calling to question the safety of flying in low grade hypoxia conditions for extended periods of time, and the potential for impairment which is not easily identifiable to the pilot.

Hypoxia event analysis outside of NTSB investigated accidents or incidents and ASRS reports, to include statistics on hypoxia frequency or severity in general aviation operations, is limited. It is suspected that this may be due to cultural attitudes of invulnerability toward hypoxia within the general aviation community, lack of awareness of hypoxia symptoms, lack of willingness to voluntarily report, or lack of reporting due to no regulatory requirement to do so (Schindler, 2017). In a study focusing on hypoxia reporting of general aviation pilots, 343 general aviation pilots completed a survey assessing their hypoxia event history. 200 pilots answered 'yes' to having a hypoxia event in-flight. Of those answering "yes", 15% of respondents reported having a hypoxic event between 0 and 10,000 feet MSL, while 71% reported a hypoxic event between 10,000 and 20,000 feet MSL. When asked whether the pilot reported the hypoxia incident, over 90% responded they had not reported the event (Holt, Luedtke, Carr, Perry, Hight, Schindler, & Ward 2017). Although this survey represents a limited population of general aviation pilots, the indicated lack of reporting illustrates a potential safety concern as to how often and severe hypoxia incidents occur. Subsequently, such events may not be actively mitigated due to the lack of reporting amongst the general aviation community.

Physiological Training Requirements

Federal Aviation Regulations do not require special hypoxia or other practical physiological training (i.e. by demonstration) for pilots under Parts 91, 121, or 125. Knowledge of aviation aeromedical factors are discussed in the Federal Aviation Administration's Pilot's Handbook of Aeronautical Knowledge, to include topics such as hypoxia, middle ear and sinus problems, spatial disorientation, and illusions (Federal Aviation Administration, 2016). This information provides aviators with an introductory level of knowledge on pertinent aviation physiology topics which are often encountered by general aviation pilots. The information is intended to bring a basic level of awareness to physiological factors, and leaves aviators to pursue elective or supplemental training as they see fit.

Title 14 of the Code of Federal Regulations (CFR) part 61, §61.31(g) describes additional physiology training that is required for pilots seeking to operate aircraft with a service ceiling or maximum operating altitude above 25,000 feet MSL. Pilots intending to operate at these altitudes must undergo physiological ground training from an authorized instructor and obtain an endorsement certifying satisfactory completion of the training. According to 14 CFR §61.31 (g), this training must include the following topics:

- Aerodynamics and meteorology in the high-altitude environment
- Respiration
- Hypoxia and the symptoms, causes, and effects
- Other forms of high-altitude sickness
- Time of consciousness without supplemental oxygen

- Gas expansion and bubble formation causes, effects, and preventative measures
- Decompression and the physiological factors associated

Additionally, pilots must also complete a flight training portion for the high-altitude endorsement. This training may be completed in a flight simulator but must include normal cruise operations while operating above 25,000 feet MSL, emergency procedures for simulated rapid decompression, and emergency descent procedures (Title 14 of the CFR Part 61, §61.31(g), 2019).

While the requirements of 14 CFR § 61.31 (g) only apply to those pilots operating pressurized aircraft capable of high altitude operations, Advisory Circular (AC) 61-107B "highly recommends" the training for all pilots who fly at altitudes above 10,000 feet MSL (Department of Transportation, FAA, 2015). Further, it provides a warning to pilots for actions that should be taken in the event that hypoxia is suspected, as well as physiological signs and symptoms which may indicate hypoxia. However, no regulatory requirement presently exists for practical (applied) hypoxia awareness training.

Hypobaric Chamber Training

To educate pilots on critical physiological topics and to familiarize individuals with hypoxia symptoms and recognition, hypobaric chamber training (HCT) has been made available to civilians since the mid 1960's. Primarily used by the military for several decades, HCT facilities are used to simulate the reduction in barometric pressure with altitude. Due to the highly varying nature of hypoxia and how the condition manifests in each person, the primary purpose of HCT is to give participants the opportunity to experience their own personal symptoms of hypoxia in a controlled environment (Aerospace Medical Association Civil Aviation Subcommittee, 2008). In some courses, participants also experience a rapid decompression event. The symptoms experienced by participants inside the hypobaric chamber are an accurate reflection of those encountered during acute hypoxia (Self, Mandella, Prinzo, Forster, & Shaffstall, 2010).

HCT training is generally conducted in a chamber accommodating six to 20 participants and two to three inside safety observers. The mechanics of the chamber are either computer controlled or are manipulated by a trained chamber operator. High altitude chambers utilize a vacuum pump to lower the pressure inside the chamber, which is done with increasing altitudes to simulate real-world conditions (Self et al., 2010). Many HCT facilities have a set flight profile, which outlines training procedures and altitude specifications.

Along with several private facilities and a select few military installations nationwide, the Federal Aviation Administration's Civil Aerospace Medical Institute (CAMI) offers a one-day course for HCT for participants in possession of a valid Federal Aviation Administration medical certificate. The course includes a required academic ground lesson where topics such as physics of the atmosphere, gas laws, hypoxia, respiration, visual illusions, spatial disorientation, and other related topics are discussed (Federal Aviation Administration, 2015). The participants are then allowed to take part in a seven-part HCT flight. As part of the preliminary safety information, participants first undergo a pre-flight briefing to become familiarized with the procedures of the chamber flight. Participants are then briefed and required to demonstrate correct usage of the oxygen equipment to be used during the flight. Once occupants are familiar with the operation of equipment and complete a period of breathing 100% oxygen to reduce the likelihood of decompression sickness, an ear and sinus check at approximately 6,000 feet is conducted. This is done to ensure each participant is able to clear their ears and sinus prior to the start of ambient pressure changes. Upon successful demonstration, the chamber undergoes a rapid decompression. The decompression is demonstrated through a climb from 8,000 feet to 18,000 feet in approximately 8 to 10 seconds (Federal Aviation Administration, 2015).

Following the rapid decompression, the chamber continues to ascend to 25,000 feet. Upon reaching the specified altitude, participants remove their oxygen mask and remain without supplemental oxygen for up to five minutes. Symptoms of hypoxia begin to appear within the five-minute time period, during which participants assess their symptoms and increasing impairment through the completion of basic math or other cognitive reasoning tasks, such as putting shapes into a cube or counting backwards in intervals. As participants begin to accumulate symptoms which they would recognize in an airplane they are instructed to treat themselves for hypoxia, at which time they must demonstrate the correct sequence of equipment initiation; this includes turning the oxygen regulator to the ‘emergency’ position and donning their oxygen mask. During the training participants are monitored with pulse oximeters to measure their oxygen saturation and heart rate, to preclude excessive conditions such as dangerously low oxygen saturation or tachycardia (an excessively fast heartbeat) (Harmon, 2010).

Recurrent HCT every three to six years is considered a suitable timeframe to refresh the knowledge learned, with emphasis on the early (and often subtler) symptoms of hypoxia (Neuhaus & Hinkelbein, 2014).

Hypobaric Chamber Training Risks

A 23-year reporting period on HCT physiological reactions from individuals participating at an FAA HCT facility revealed the most common unintended conditions encountered were aerotitis media (ear pain), aerosinusitis (sinus pressure), aerodontalgia (toothache), abdominal distress, and hyperventilation. Decompression sickness was also observed in ten participants out of 12,759 (Valdez, 1990).

Nitrogen is an inert gas which is stored in the tissues within the human body (Brown & Antuñano, 1995). Exposure to low barometric pressure can cause the nitrogen to transition out of a solution to small bubbles. These bubbles are the cause of decompression sickness (DCS). Due to the pressure variations experienced during an HCT flight, participants can develop DCS. To reduce the risk of potential DCS, participants breathe 100% oxygen for, on average, 30-60 minutes prior to ascent (Ottestad, Hansen, Pradhan, Stepanek, Hoiseth, & Kasin, 2017). The denitrogenation process assists to eliminate nitrogen from the body's tissue thereby reducing the likelihood of DCS occurrence (Brown & Antuñano, 1995).

Decompression sickness is cited in the literature as one of the primary risks of high-altitude chamber training use (Hackworth, Peterson, Jack, Williams, & Hodges, 2003), however, research focusing on the DCS rate amongst HCT participants indicates a low rate of occurrence. A study conducted over a 63-month period to calculate the incidence rate for decompression sickness of participants revealed 0.64/1000 exposures (Piwinski, Cassingham, Mills, Sippo, Mitchell, & Jenkins, 1986). A similar study of DCS rates within a U.S. Navy HCT facility reflected a DCS incidence rate among participants of 78 cases out of 111, 674 exposures (incidence rate of 0.07%) (Bason & Yacavone, 1991).

Although participants experience varying degrees of physiological reactions during HCT training, mild reactions are expected, and research indicates that the training provides a safe learning environment without compromising the health and safety of the student (Valdez, 1990).

Normobaric Hypoxia Training

As an alternative to hypobaric chamber training, normobaric training was developed to provide a similar training experience through the use of a reduced oxygen breathing device (Artino, Folga, & Vacchiano, 2009). Participants of normobaric training breathe mixed gases which induce hypoxia; such facilities are used as a less expensive and more portable method of hypoxia recognition training. Research has been conducted to analyze differences between hypobaric and normobaric methods of hypoxia training. However, analysis of the normobaric method will not be included in this review.

HCT Implications for Training Standards

Experiencing the effects of hypoxia during an altitude chamber flight can greatly improve the ability to recognize hypoxia (Federal Aviation Administration, 2017). The ability to recognize hypoxia is critical to prevent incapacitation and to enable corrective actions before a safety incident or accident occurs (Cable & Westerman, 2010). However, current FARs do not require high altitude chamber training for any type of airman certification or training. Despite any regulatory requirement, HCT is considered to be beneficial; with a principle element of hypoxia awareness training being the evocation of hypoxia symptoms (Neuhus & Hinkelbein, 2014).

A survey and analysis conducted by the Federal Aviation Administration in 1991 to determine if training in high altitude physiology should be required for civilian pilots concluded that there is a need for further training for all civilian pilots intending to fly above 5,000 feet at night or 10,000 feet in the day (Turner & Huntley, 1991). This conclusion was reached after assessment of current standards for training, incident and accident reports, interviews with aviation trade organizations, airlines, unions, airframe manufacturers, flight schools, and the military, and analysis of content that should be included in an ideal curriculum. The study stated through adequate implementation and anticipation of training needs, "physiologically-related accidents can be eliminated before they happen." (Turner & Huntley, 1991).

Research related to the effectiveness of HCT and the transfer of knowledge to the cockpit is documented largely through the analysis of military usage. In an analysis of hypoxia incidents documented by the United States Air Force over a 14-year period, 656 reports were received, with 606 of the reports involving crews who had undergone HCT (Cable, 2003). Of the HCT trained crews, 3.8% lost consciousness, while 94% of passengers involved in the incident who had not undergone HCT lost consciousness (Cable, 2003). The ability to recognize the symptoms of hypoxia were attributed to HCT the crews had undergone as part of their military training, with the study concluding that the resulting difference between trained aircrew and untrained passengers highlights the benefit of hypobaric chamber training for the recognition of hypoxia (Cable, 2003). A similar analysis was conducted over an 11-year period for Australian military aircrews.

Twenty-seven reports, encompassing 29 crews, of hypoxia were received over the reporting period, with approximately 75% of the crewmembers having recognized their symptoms of hypoxia (Cable, 2003).

In another approach to analyzing the potential need for high altitude chamber training, a study was conducted to understand the hypoxia training backgrounds, experiences, and perceptions of 62 pilots, who voluntarily participated in a multi-question survey. Categories of questions included demographics, pilot training experiences, and pilot attitudes on hypoxia training requirements (Hackworth et al., 2003). Of the total number of respondents (more than one answer was selectable), 61% reported having attended a basic introductory course on hypoxia, 34% had attended a recurrent course on hypoxia, and 71% reported having attended HCT; 97% of the respondents reported their training was informative, while 85% of the respondents felt that all pilots should receive an initial altitude chamber course, and 80% stated all crewmembers should (Hackworth et al., 2003). Further, 52% of the sample disagreed that current regulations addressing high altitude flying were sufficient.

Limitations of the study included generalizability of the results due to the limited sample size. While some inferences may be drawn in the statistics presented, to better understand whether individuals from various sectors within the aviation industry see similar need for HCT as presented in the aforementioned study, analysis from a greater number of pilots is needed.

Purpose of the Study

The purpose of this research is to determine the perspectives of high altitude chamber training participants in regard to hypoxia perceptions, training experience, and attitudes towards hypoxia training requirements. The following research questions are intended to be addressed:

- Do previous participants of HCT support the use of the training?
- Do participants feel the training made them a safer operator?
- Do participants believe HCT should be required training?

The research aims to fill the void identified in current literature surrounding feedback from high altitude chamber training participants, in order to further the literature related to potential methods of aviation physiological training improvement.

The hypothesis for this study is participants support the use of high altitude chamber training and its application to the improvement of safety, due to the gained skill of hypoxia recognition.

CHAPTER 3

Methodology

Participants

Responses to hypoxia and regulatory perceptions, high altitude chamber training experience, and attitudes toward the safety and use of HCT amongst pilots were assessed through the collection of responses to an anonymous survey. Potential survey respondents were identified through having completed an HCT course hosted at the Del E. Webb High Altitude Chamber at Arizona State University. Potential respondents were also recruited through social media outlets of a business aviation training company and subscribers of the Curt Lewis & Associates Flight Safety Information newsletter. Respondents were contacted by either direct email or solicitation for participation via newsletter or social media. All potential participants for the survey were required to affirm being over the age of 18 and have previously completed HCT. Individuals which did not meet both requirements were disqualified from completing the survey.

A total of 123 responses were collected in the survey; however, ten respondents were disqualified for not having completed HCT training, one respondent did not answer any questions, and two respondents completed only two demographic questions. For the purpose of the data analysis, N=110.

Research Materials

A 24-question closed-ended, Likert scale-type survey was developed and disseminated via Qualtrics (see appendix B). Nine demographic questions and 15 survey questions were asked of participants. Demographic information included previous training history, purpose for training, highest pilot certificate held, profession, student status, age, and gender.

A letter stating the purpose of the study, approval by the Arizona State University Human Subjects Institutional Review Board, and consent for use of participant response in the study was presented at the beginning of the survey. Respondents were required to provide consent prior to the start of the survey. The letter/consent form is located in appendix A.

Categories of Questions

To aid in organization, survey questions were divided into three categories: perceptions, experience, and attitudes. Five questions were assigned to each category. Perception questions related to the respondent's views on general hypoxia awareness and training. Experience questions related to the respondent's HCT experience and resulting awareness of hypoxia factors. Attitude questions related to the respondent's views on resulting safety implications and recommendation for the training for others. To assist in establishing the face validity of the survey questions, the questions were submitted to a subject matter expert for review.

CHAPTER 4

Results

This chapter discusses the results of the survey responses. Question one listed the consent required by participants. Demographic information was collected in questions two through nine. No cross correlations including demographic information were considered. All responses to demographic questions are displayed in appendix B.

Data and Analysis

A one sample t-test was performed on each question, comparing the responses against a test value of 3 (neutral); to evaluate whether the mean of the data was significantly different from neutral. Survey answer choices were coded on a scale of strongly agree (1), agree (2), neither agree nor disagree (3), disagree (4), strongly disagree (5). The following results include the survey questions and their mean, standard deviation, and significance. If a Bonferroni critical adjustment was made to keep the experiment-wise type 1 error below .05, the p-value would be 0.003 for each test. Additional data resulting from each one-sample t-test and statistics is located in appendix C.

Demographic Questions

Question 1. *Consent to participate*

100% of participants consented to participate in the study. Refusal to provide consent would have resulted in disqualification from participation.

Question 2. *Have you previously completed high altitude chamber training?*

Ten respondents indicated they had not previously completed high altitude chamber training and were disqualified from participation. All remaining respondents indicated they had previously attended HCT.

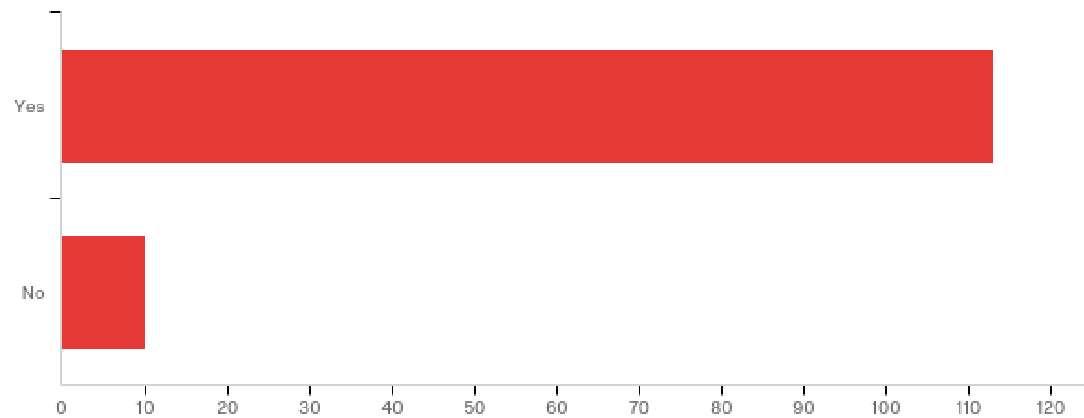

Figure 3. Previous HCT Experience

Question 3. *When did you last complete high altitude chamber training?*

Most respondents had completed high altitude chamber training over 12 months ago; approximately 28.8% had completed the training within the past 12 months.

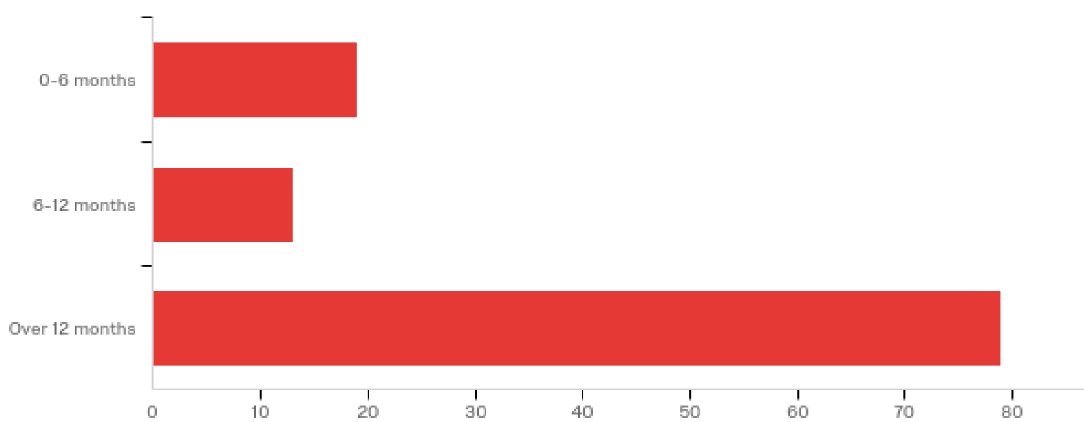

Figure 4. Interval of Previous Training

Question 4. *What was your primary purpose for attending high altitude chamber training?*

Approximately 46% of respondents had attended HCT due to a requirement from their employer, followed by 31.6% attending for elective training.

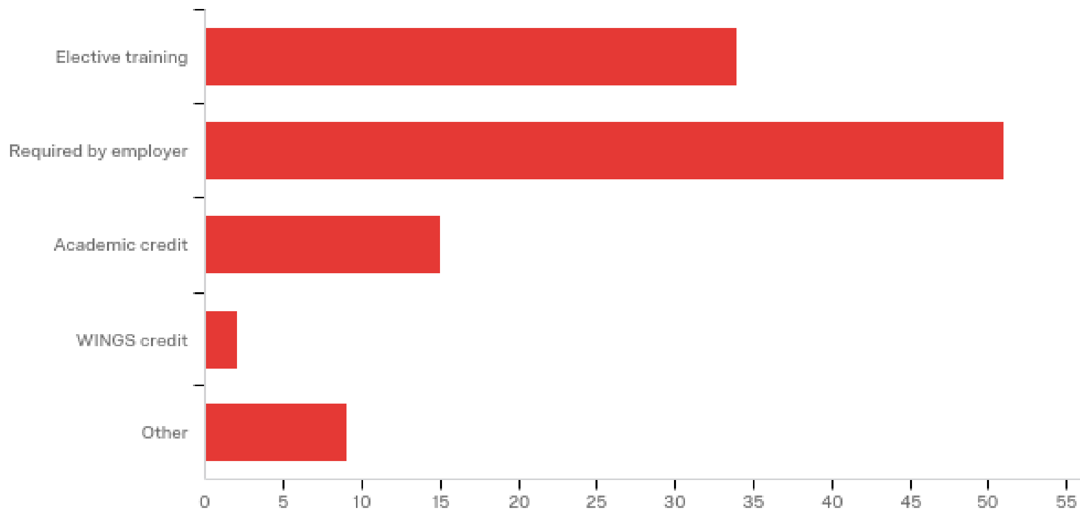

Figure 5. Purpose for Attending HCT

Question 5. *What is your highest pilot certificate held?*

A range of pilot certificates were indicated by participants. Most commonly held was an Airline Transport Pilot certificate, followed by commercial pilot ratings, and flight instructors.

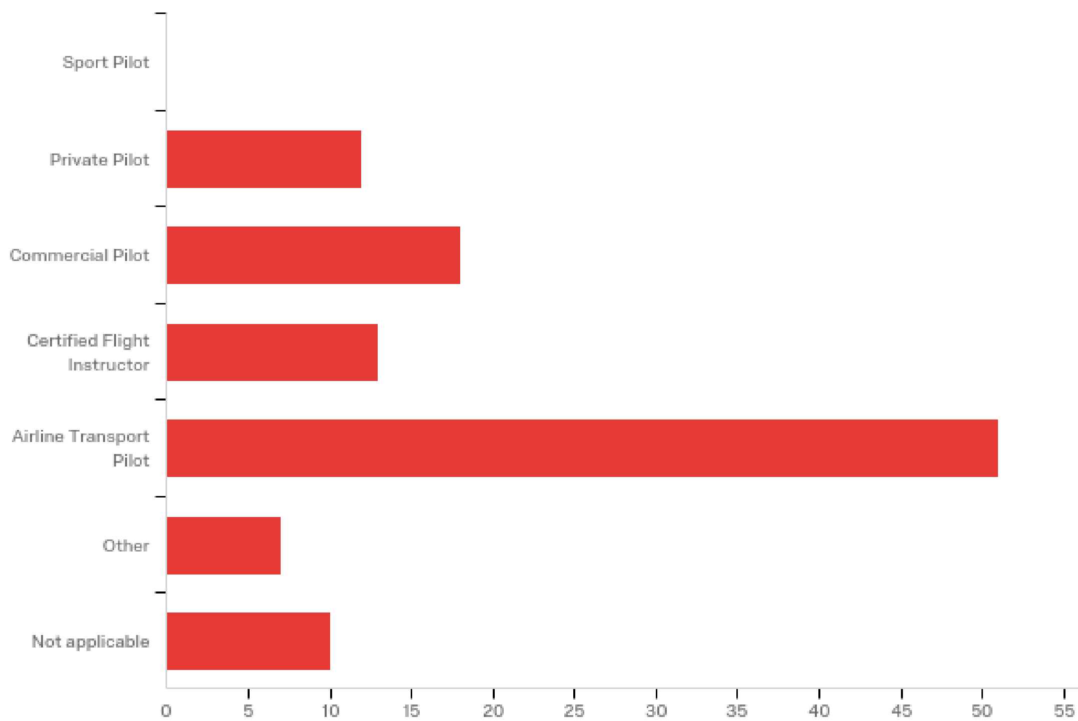

Figure 6. Highest Pilot Certificate Held

Question 6. *What is your profession?*

Reponses included pilots (student, corporate, airline, military, test, flight instructor, helicopter, and other general aviation pilots). Also indicated was a sky dive instructor, Senior Aviation Analyst, Flight Operations Safety Manager, Loadmaster, Aerospace Engineers, Flight Test Engineers, Dispatcher, A&P Mechanic, FAA Aviation Safety Inspector, Airline Safety Evaluator, Air Traffic Control Specialist, and a Flight Surgeon.

Profession Category:	Number of Responses:
Pilot	50
Engineer	15
Aviation - Other	21
Student	5
Other Profession	12

Figure 7. Profession of Respondents

Question 7. *What is your current student status?*

Most respondents were not current students; 16.2% indicated full or part-time student status.

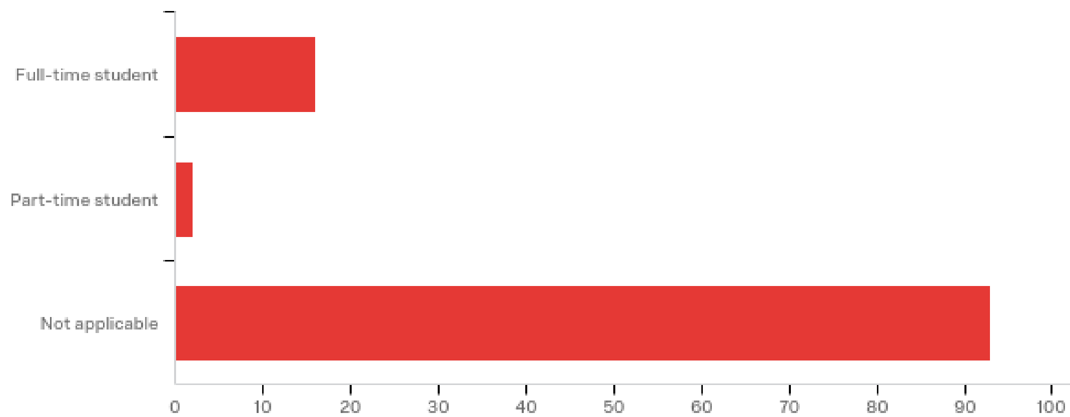

Figure 8. Student Status

Question 8. *What is your age?*

The age of respondents ranged from 19 to 88. The average age of participants was 47.

Age:	Number of Respondents:	Age:	Number of Respondents:
19	1	54	3
20	2	55	6
21	4	56	2
22	8	57	1
23	4	58	3
24	3	59	5
25	1	60	2
27	1	61	3
28	1	62	2
29	1	63	5
30	2	64	3
31	3	65	2
32	2	66	2
33	1	68	1
34	1	69	2
35	4	70	2
37	1	72	2
39	1	73	1
41	1	74	2
47	1	75	1
48	1	76	1
50	4	84	1
52	3	88	1
53	1	over 60	1

Figure 9. Respondent Age

Question 9. *What is your gender?*

The majority of respondents were male; 8.2% of respondents were female.

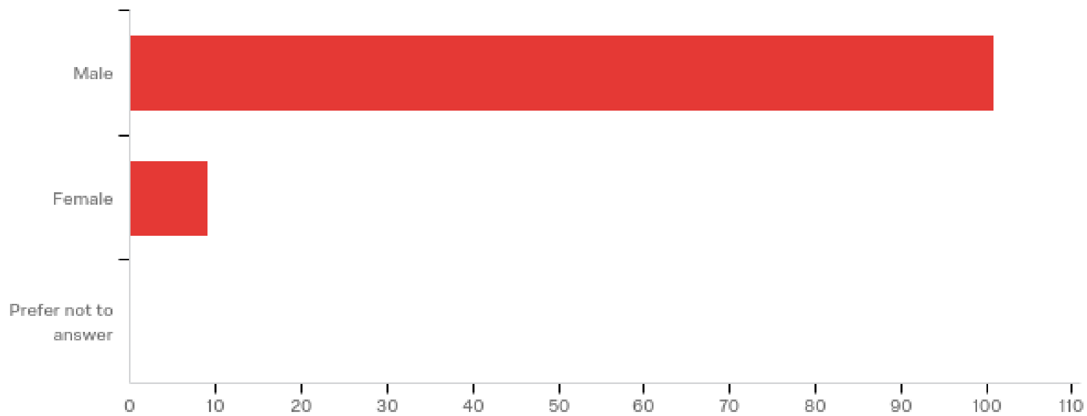

Figure 10. Gender

Perceptions

Question 10. *Hypoxia affects pilots most often when flying above 25,000 feet.*

Approximately 53.6% of respondents agreed hypoxia affects pilots most often above 25,000ft; followed by 30% of respondents who disagreed.

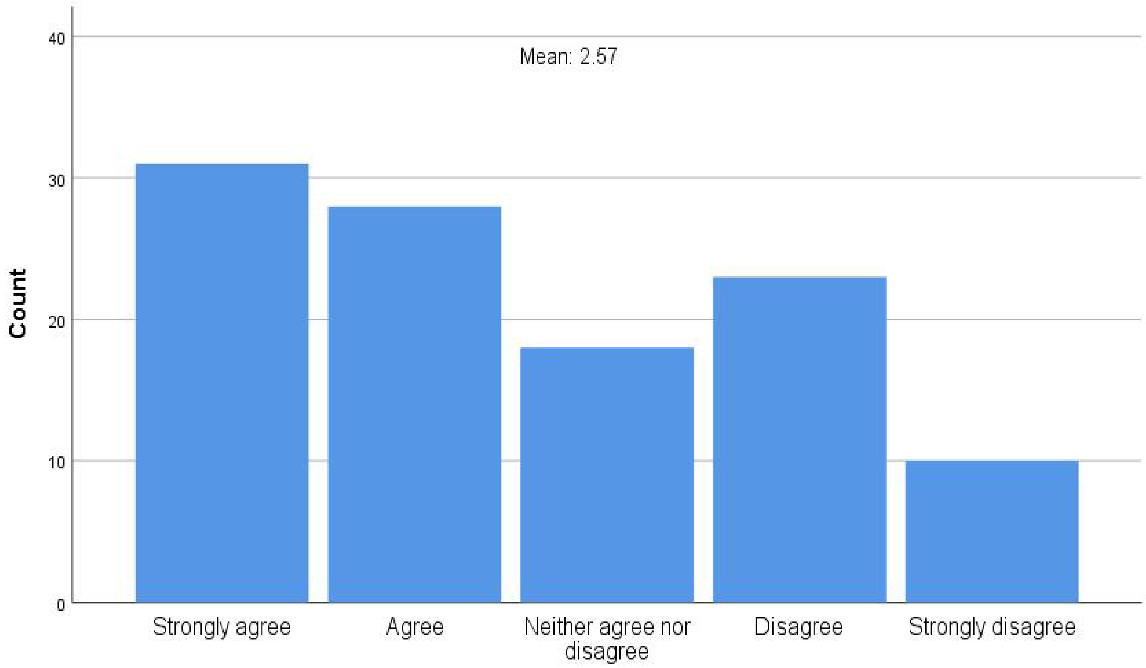

Figure 11. Survey Question 10

(M = 2.57, SD = 1.337, $p < .001$)

Question 11. *Current Federal Aviation Regulations allowing pilots to fly with cabin altitudes up to 12,500 feet MSL, or up to 14,000 feet MSL for up to 30 minutes without supplemental oxygen are sufficient to prevent hypoxia.*

Responses varied amongst participants as to regulatory effectiveness to prevent hypoxia, with 46.3% agreeing current regulations are sufficient and 36.4% disagreeing.

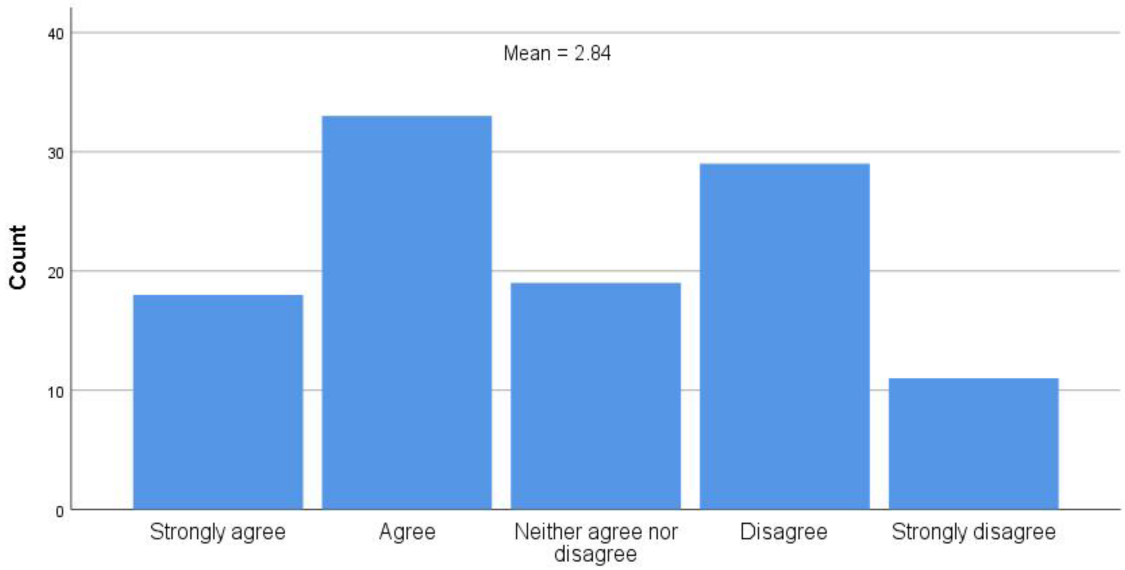

Figure 12. Survey Question 11

($\underline{M}$ = 2.84, $\underline{SD}$ = 1.267, $\underline{p}$ =.178)

Question 12. *Classroom-based aviation physiology training provides insufficient knowledge for hypoxia recognition.*

The majority of respondents (60%) agreed classroom-based training was insufficient for hypoxia recognition training.

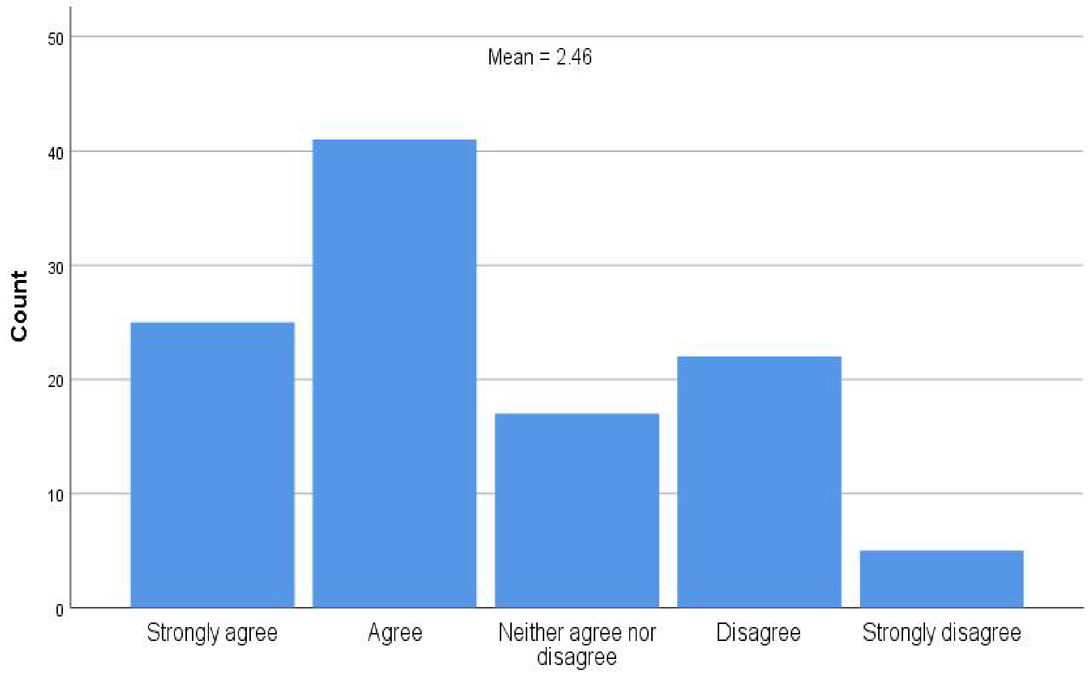

Figure 13. Survey Question 12

(M = 2.46, SD = 1.178, $p < .001$)

Question 13. *It is important to know my own symptoms of hypoxia.*

No responses were received for the disgree and strongly disagree answer choices. Nearly all respondents agreed it is important to know their symptoms of hypoxia, as indicated by agreement by 99% of respondents.

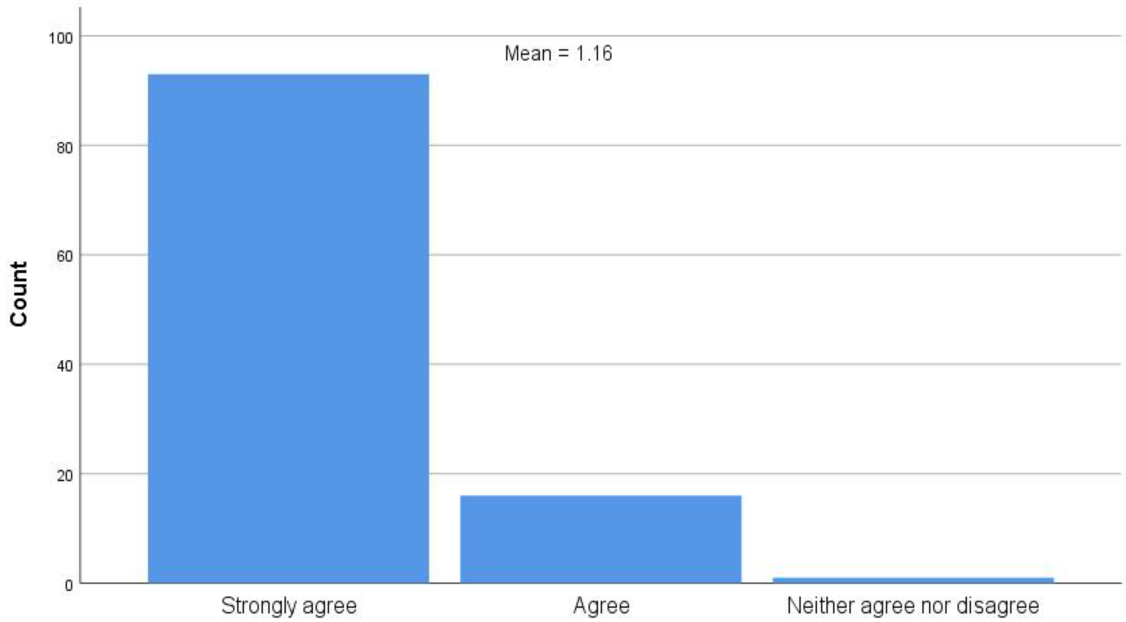

Figure 14. Survey Question 13

(M = 1.16, SD = .396, $p < .001$)

Question 14. *The possible effects of hypoxia are not of concern to me below 14,000 feet.*

A majority of respondents indicated concern with possible hypoxia effects below 14,000 feet, as indicated by agreement from 83.7% of respondents.

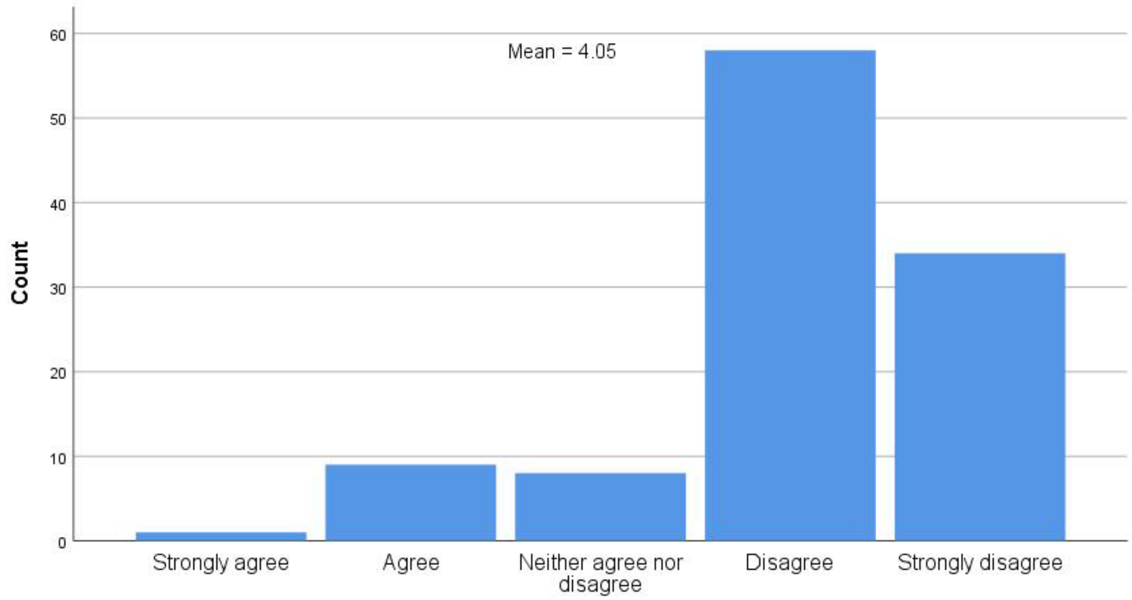

Figure 15. Survey Question 14

(M = 4.05, SD = .892, $p < .001$)

Experience

Question 15. *Prior to participating in high altitude chamber training, I am confident I would have recognized my symptoms of hypoxia, if they would have occurred.*

Inquiry as to whether respondents believe they would have recognized their symptoms of hypoxia prior to HCT revealed 20% of individuals indicating they would have, while 70.9% indicated they would not have.

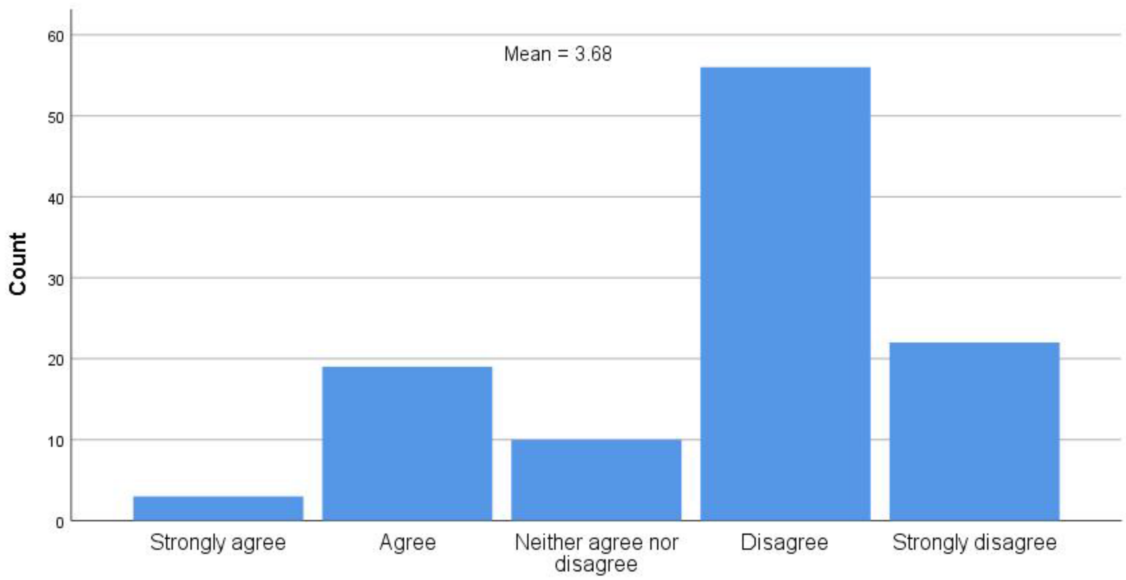

Figure 16. Survey Question 15

($\underline{M} = 3.68$, $\underline{SD} = 1.066$, $\underline{p} < .001$)

Question 16. *After participating in high altitude chamber training, I am confident I would recognize my symptoms of hypoxia, if they were to occur.*

No responses were received for the strongly disagree answer choice. Most respondents (83.7%) indicated they believed they would recognize their symptoms of hypoxia after HCT; 1.8% of respondents indicated they would not recognize their symptoms.

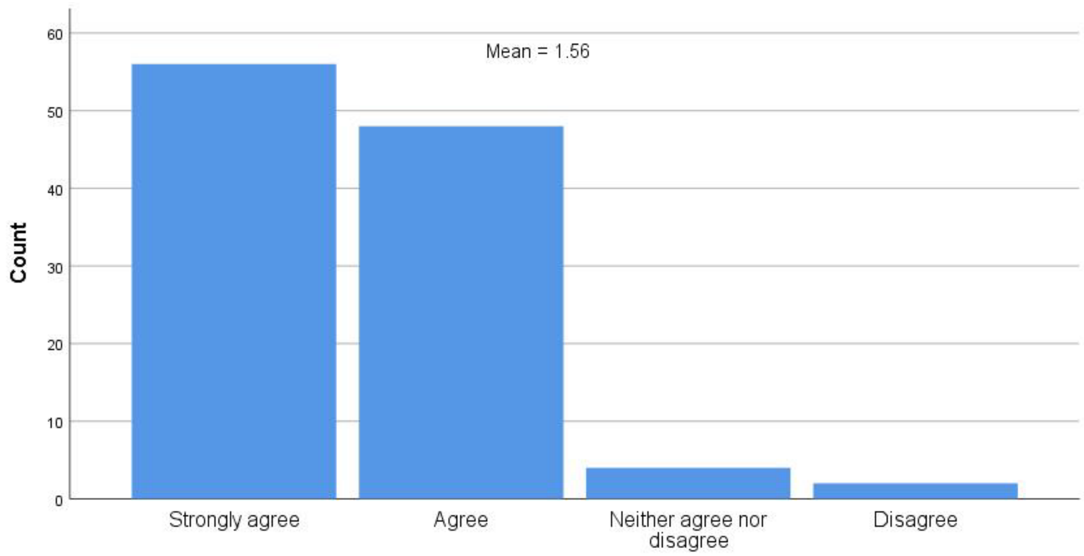

Figure 17. Survey Question 16

($\underline{M} = 1.56$, $\underline{SD} = .657$, $\underline{p} < .001$)

Question 17. *I am a safer pilot, crewmember, or other support personnel for having attended high altitude chamber training.*

No responses were received for the disagree or strongly disagree answer choice. The majority of respondents, 96.8%, indicated they felt they were safer due to attending HCT.

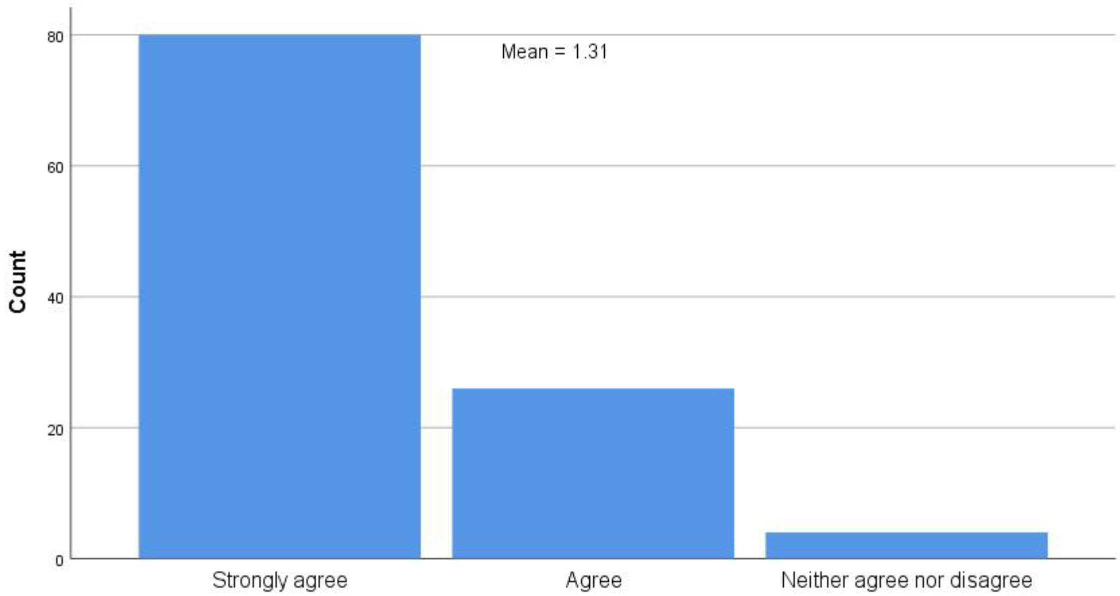

Figure 18. Survey Question 17

(M = 1.31, SD = .538, $p < .001$)

Question 18. *High altitude chamber training provided a training experience which would be difficult to replicate in solely classroom-based training.*

No responses were received for the strongly disagree answer choice. The majority of respondents indicated HCT would be difficult to replicate in classroom training, as interpreted by agreement in 98.2% of respondents.

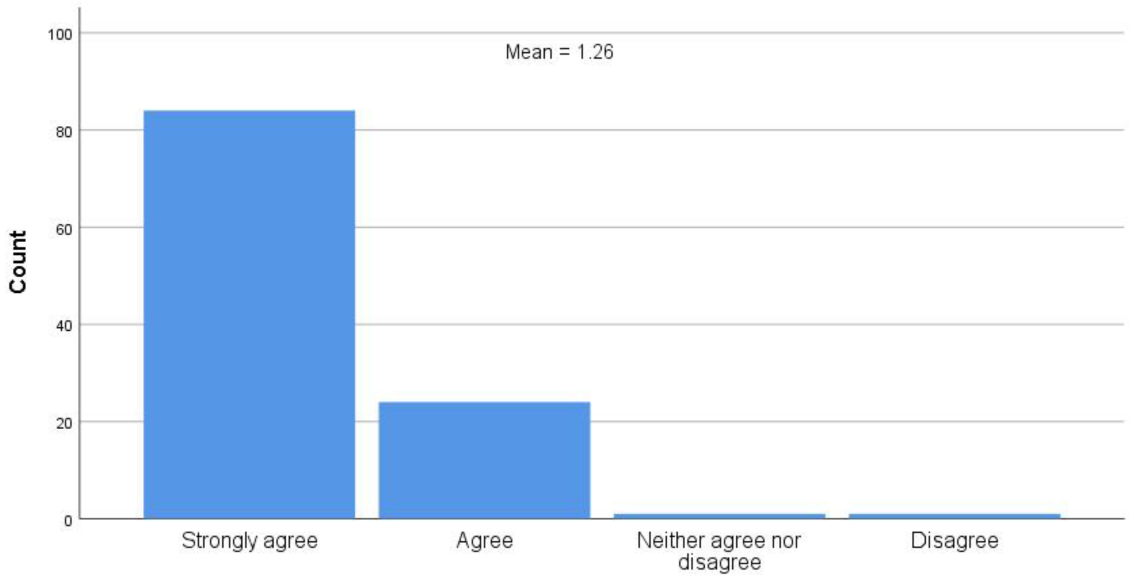

Figure 19. Survey Question 18

(M = 1.26, SD = .519, $p < .001$)

Question 19. *High altitude chamber training presents an unnecessary risk for participants.*

Approximately 85.5% of respondents indicated HCT was not an unnecessary risk; 3.64% felt the training was an unnecessary risk.

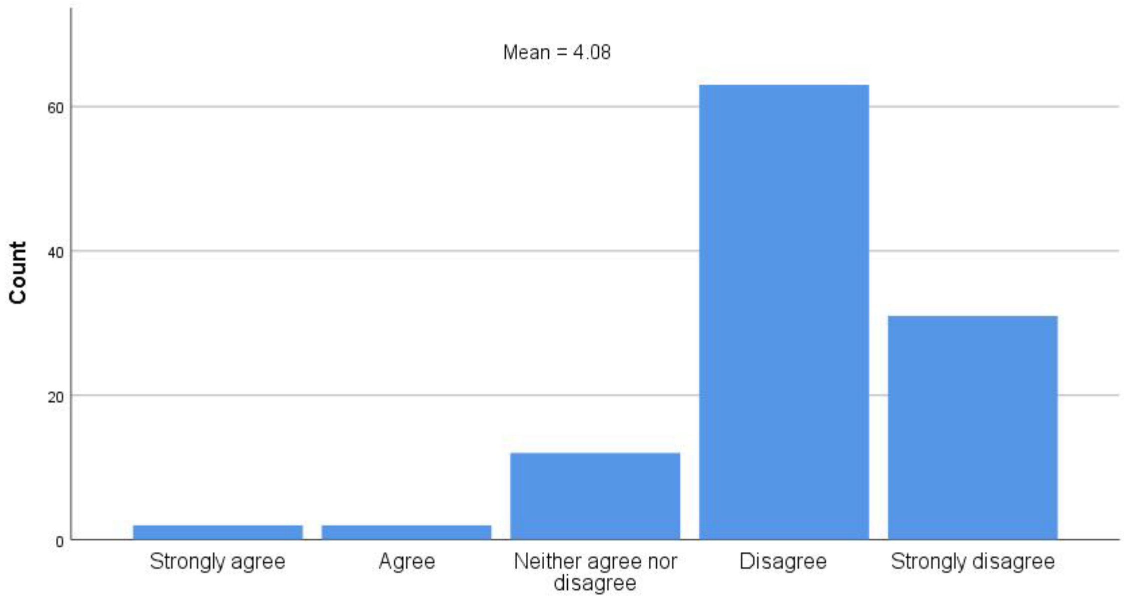

Figure 20. Survey Question 19

($\underline{M} = 4.08$, $\underline{SD} = .791$, $\underline{p} < .001$)

Attitudes

Question 20. *I would recommend high altitude chamber training to other pilots or interested individuals.*

No responses were received for the disagree or strongly disagree answer choice. Nearly all respondents (99%) would recommend HCT to others.

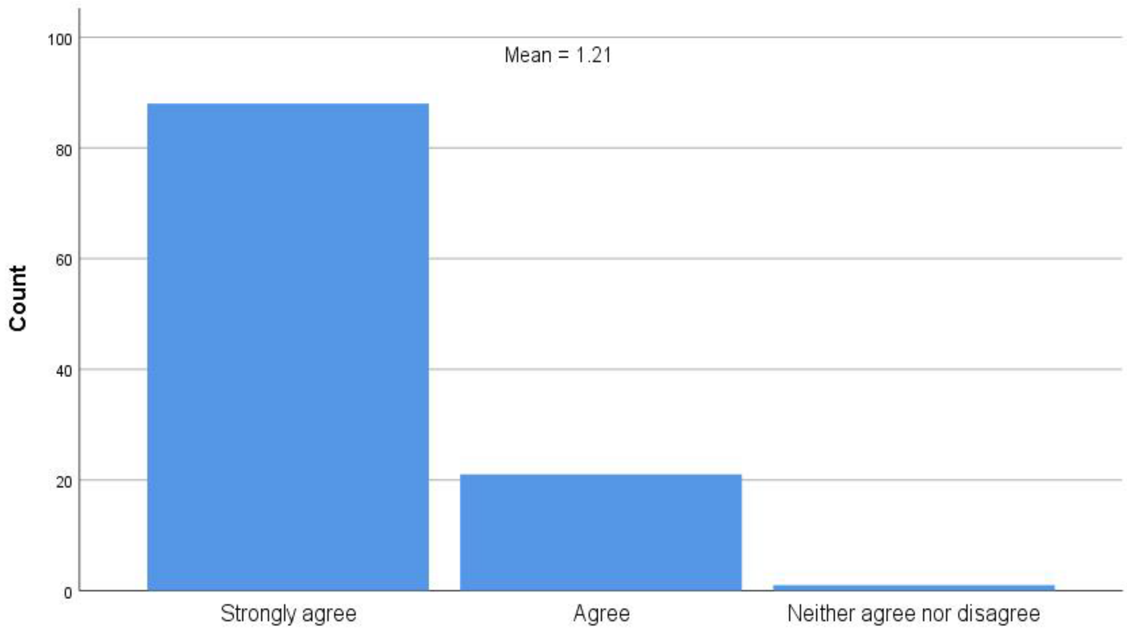

Figure 21. Survey Question 20

(M = 1.21, SD = .430, $p < .001$)

Question 21. *I would feel safer as a passenger knowing the pilot/s had undergone high altitude chamber training.*

No responses were received for the disagree or strongly disagree answer choice. The majority of respondents indicated they would feel safer as a passenger with pilots who had HCT experience, as indicated by agreement by 92.3% of respondents.

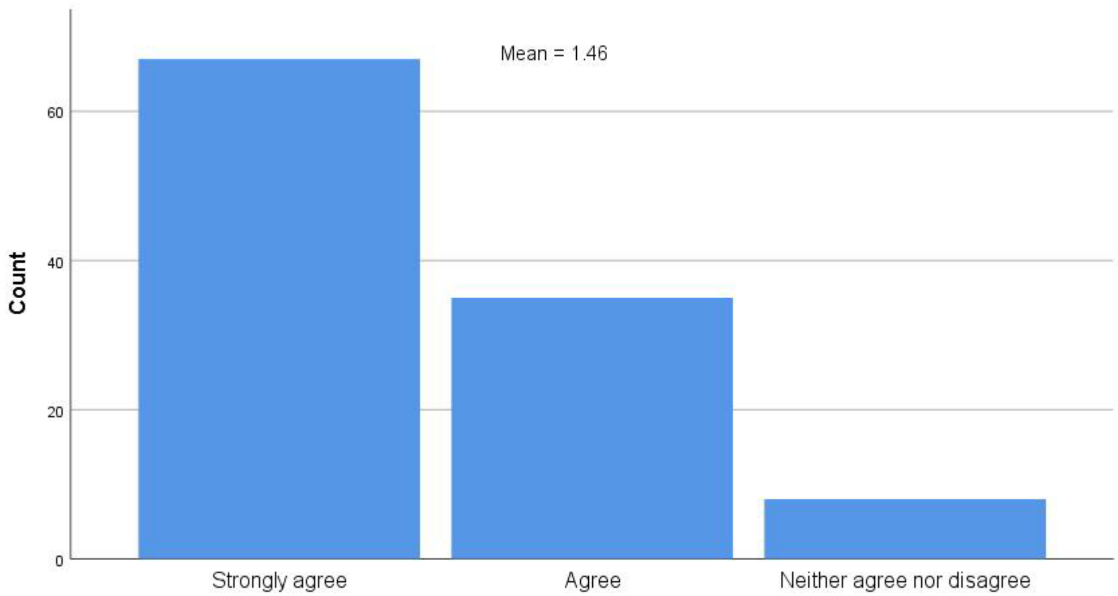

Figure 22. Survey Question 21

(M = 1.46, SD = .631, $p < .001$)

Question 22. *All pilots should receive initial high altitude chamber training.*

No responses were received for the strongly disagree answer choice. A majority (74.5%) of respondents felt pilots should receive intial HCT; 10% indicated pilots should not receive intial HCT.

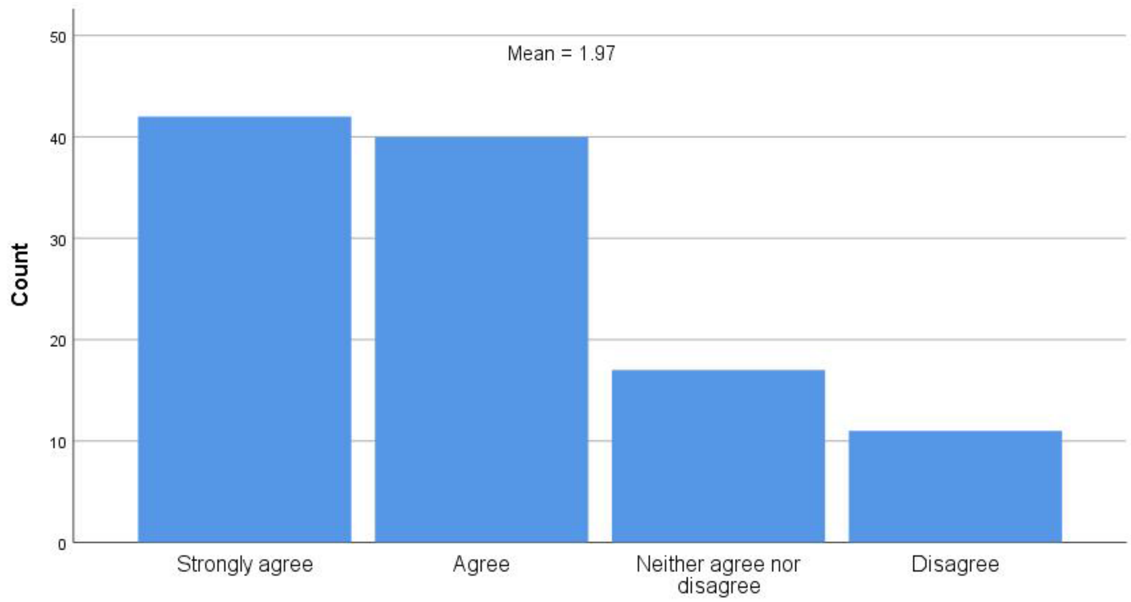

Figure 23. Survey Question 22

($\underline{M}$ = 1.97, $\underline{SD}$ = .972, $\underline{p}$ < .001)

Question 23. *All pilots should receive recurrent high altitude chamber training.*

Half of respondents felt pilots should receive recurrent HCT, while 20.9% of respondents indicated pilots should not receive recurrent HCT.

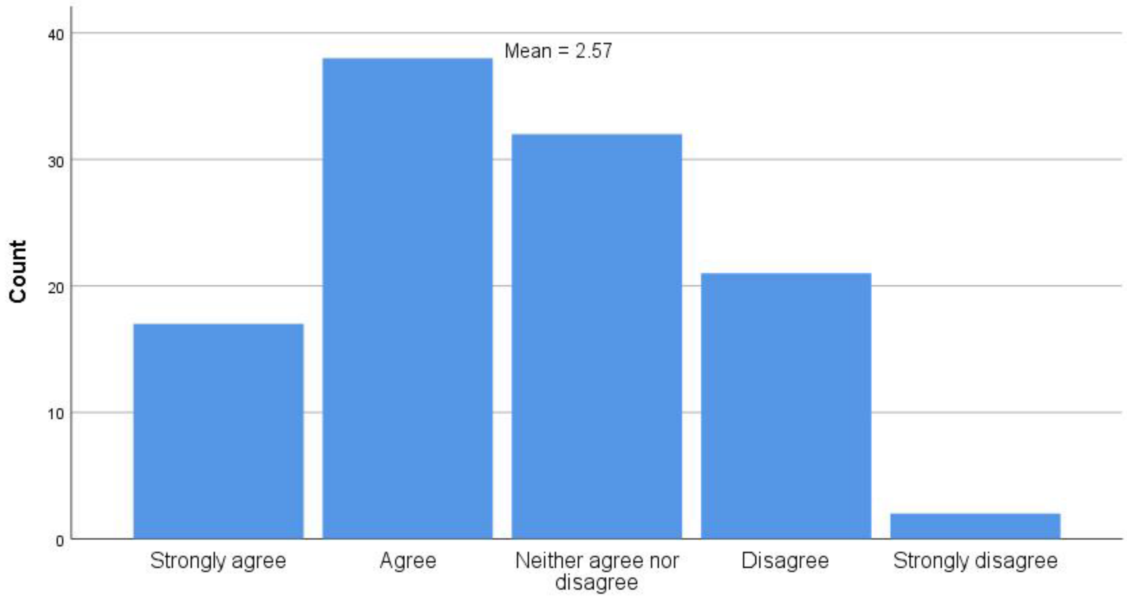

Figure 24. Survey Question 23

(M = 2.57, SD = 1.027, $p < .001$)

Question 24. *High altitude chamber training should remain elective training under Federal Aviation Regulations.*

Results revealed 40% of respondents disagree that HCT should remain elective training, while 28.2% neither agree nor disagree and 31.8% disagree.

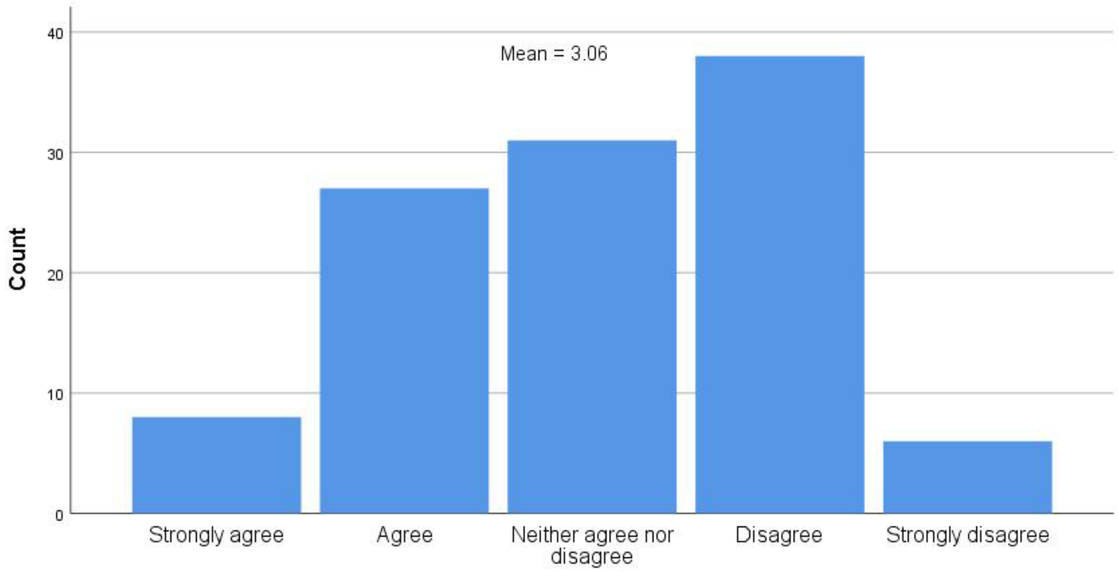

Figure 25. Survey Question 24

(M = 3.06, SD = 1.052, p =.527)

CHAPTER 5

Discussion

The purpose of this study was to analyze the perceptions toward hypoxia regulations and awareness, experience of high altitude chamber training, and attitudes toward hypoxia training requirements and safety from individuals who had previously completed high altitude chamber training. The data from the survey revealed significant results from each of the three categories of questions (perceptions, experience, and attitudes).

Non-significant results were found in question 11 stating *Current Federal Aviation Regulations allowing pilots to fly with cabin altitudes up to 12,500 feet MSL, or up to 14,000 feet MSL for up to 30 minutes without.* Question 24 stating H*igh altitude chamber training should remain elective training under Federal Aviation Regulations* also revealed non-significant results. The commonality in these two questions were formal oversight by the Federal Aviation Administration; however, both questions were exceptions to an otherwise majority of agreement of knowledge value, safety, and recommendation for the use of HCT.

Perceptions

A majority (53.6%) of respondents answered strongly agree or agree that hypoxia affects pilots most often when flying above 25,000 feet. This result indicates the belief that hypoxia affects pilots most often at higher altitudes. Although the onset quickness and severity of hypoxia can be greater at higher altitudes, current hypoxia training practices may not adequately discuss dangers that occur at lower altitudes, despite research which indicates hypoxia, including low-grade hypoxia, can lead to impairment

(Nesthus, Rush, and Wreggit, 1997). Similar to the 1991 Hackworth study, 46.3% of respondents answered strongly agree or agree that Federal Aviation Regulations regarding supplemental oxygen use are sufficient to prevent hypoxia; 36.4% strongly disagreed or disagreed, and 17.3% neither agreed nor disagreed. No significance was found; however, this distribution of perception indicates a wide range of opinion regarding currently regulatory requirements. Further analysis as to the effectiveness of current regulatory requirements may be beneficial, with emphasis as it applies to general aviation operations.

A majority of respondents (60%) strongly agreed or agreed classroom-based aviation physiology training provides insufficient knowledge for hypoxia recognition, and 99% stated strongly agree or agree that it is important to know their own symptoms of hypoxia. These significant results indicate that respondents perceive strong importance in knowing their symptoms of hypoxia, but may not receive adequate classroom instruction on hypoxia recognition. This may be due to the inability to experience actual symptoms of hypoxia in a classroom setting, in which theoretical knowledge is the primary method of instruction.

Despite a majority of respondents indicating agreement that hypoxia most often affects pilots above 25,000 feet, 83.7% of respondents strongly disagreed or disagreed that the possible effects of hypoxia were not of concern to them below 14,000 feet. This significant result indicates that participants perceive importance in understanding the factors associated with hypoxia at lower altitudes, which may be beneficial to the situational and self-awareness of pilots at lower altitudes. This indicated concern from respondents may also support a future emphasis on improved physiology training, especially as it relates to potential hypoxia concerns at lower altitudes.

Experience

Approximately 20% of respondents strongly agreed or agreed they would have recognized their symptoms of hypoxia prior to participating in HCT. Comparatively, 94.6% of participants strongly agreed or agreed they would recognize their symptoms of hypoxia after participating in HCT. This represents a significant difference in the perceived ability for hypoxia symptom recognition before and after HCT. The results of these questions imply HCT may provide hypoxia recognition skills which could lead to greater in-flight self-awareness. Consistent with that interpretation, 96.8% of respondents strongly agreed or agreed that attending HCT made them a safer pilot, crewmember, or other support personnel.

The unique ability to experience hypoxia and learn hypoxia recognition techniques in HCT provides a training experience which may be difficult to replicate in classroom training. When asked whether HCT provided a training experience which would be difficult to replicate in solely classroom-based training, 98.2% of respondents strongly agreed or agreed. This significant result indicates that HCT may provide a unique, non-replicable training environment. When questioned whether HCT presents an unnecessary risk, 85.5% of respondents strongly disagreed or disagreed. This result indicates that while there are certain risks associated with HCT, the majority of respondents do not feel accepting such risk was unnecessary.

Attitudes

A significant result was found when respondents were questioned as to whether they would recommend high altitude chamber training to other pilots or interested individuals. 99% of respondents strongly agreed or agreed; indicating a strong support from prior HCT participants for the use of the training. Similarly, 92.3% of respondents strongly agreed or agreed that they would feel safer as a passenger knowing the pilot/s has undergone high altitude chamber training.

To consider respondent attitudes toward HCT training for others, 74.5% of respondents strongly agreed or agreed that all pilots should receive initial HCT; 50% of respondents strongly agreed or agreed that all pilots should receive recurrent HCT. This indicates respondents largely support the idea of all pilots receiving initial HCT, and possibly recurrent training. However, when asked whether HCT should remain elective training under Federal Aviation Regulations, a non-significant result was found; 40% strongly disagreed or disagreed, 28.2% neither agreed nor disagreed, and 31.8% agreed or strongly agreed. Further analysis as to specific reasons why respondents feel HCT should or should not remain elective training may provide insight into primary considerations (logistical, financial, etc.) which might influence their decision. Analysis of these considerations would further be beneficial in determining factors which may prevent current or future wider spread use of HCT.

The overall analysis of the responses indicate a strong support for the use of HCT by previous participants. Respondents largely indicate they achieved the training objective of HCT (to recognize hypoxia symptoms), and felt they were a safer operator due to their training. Further, the majority of respondents would recommend the training to others. Nearly 75% of respondents indicated they believed all pilots should receive initial HCT; while approximately 40% indicate agreement with having formal regulatory oversight over the training.

Limitations and Future Research

Due to limited research in the literature regarding feedback from HCT participants as to their perceptions of HCT and its usefulness, the survey asked baseline questions to provide an overall analysis of perceptions. Further research will need to be done to provide greater insight into these perceptions, to include information such as how the training has affected respondent behavior in the cockpit, or any in-flight experiences in which the respondent relied on their HCT training. Future analysis may include examining perceptions from individuals who have completed HCT more than once, and their views as to the need for recurrent HCT.

This survey was disseminated to a variety of aviation professionals, and a range of professions from collected responses were noted. This supports greater diversity in the representation from the aviation industry, however, the limited sample size of this study may inhibit greater generalizability. Future studies analyzing similar data should complete an analysis utilizing a larger sample size. This will assist will developing representative and generalizable results which can provide the necessary evidence to support actions relating to areas such as hypoxia training practices, regulatory changes, or other.

Aviation physiology knowledge and hypoxia recognition literature may also be improved by updated studies regarding HCT effectiveness, to include further analysis of susceptibility factors such as age, fitness, or health, as a method to consider training practices as it relates to individuals who may be at a greater risk of developing hypoxia in-flight.

Conclusion

Findings of this study revealed an overall positive response and support for the use of HCT for pilot training. Nearly all respondents agreed that knowing their symptoms of hypoxia are important, and nearly all agreed the training experience of HCT would be difficult to replicate in solely classroom-based training. The implications of the results indicate that HCT provides a unique training experience that teaches participants hypoxia recognition skills that may not be attainable elsewhere. Based on the results of this study, it is recommended that pilots consider their hypoxia recognition knowledge and pursue additional training, as needed.

As safety is the top priority in aviation, training which contributes to that objective is important. Consistent with this objective, the majority of respondents felt HCT made them a safer operator, and indicated they would also feel safer as a passenger knowing the pilot/s had completed HCT. Further research as described will be critical for the continued improvement of aviation physiological training practices, and subsequent reduction of related incidents and accidents.

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APPENDIX A

SURVEY CONSENT LETTER

High Altitude Chamber Training Perceptions and Experience

Dear Participant,

I am a graduate student under the direction of Dr. Mary Niemczyk in the Aviation Programs of the Fulton Schools of Engineering at Arizona State University. I am conducting a research study to examine the perceptions and experience of individuals who have completed high altitude chamber training in a hypobaric chamber. The purpose of this study is to collect data to understand whether participants of high altitude chamber training perceive the training as a tool which increases the margin of safety for pilots through hypoxia awareness.

I am inviting your participation, which will involve completing a short 5-minute questionnaire with various questions related to your perceptions of hypoxia, hypoxia training, and your experience with high altitude chamber training. You have the right not to answer any question, and to stop participation at any time.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty. You must be over the age of 18 and have previously completed hypoxia training at a high altitude (hypobaric) chamber to participate in the study. There are no foreseeable risks or discomforts to your participation.

There will be no compensation for time spent on this questionnaire. Although there is no direct benefit to you, possible benefits of your participation include greater awareness of hypoxia and its affects, and the potential for greater safety within the aviation industry as a result of improved physiological training and hypoxia awareness practices.

Your responses will be anonymous. The results of this study may be used in reports, presentations, or publications. Basic demographic questions including your age, gender, training history, and profession will be asked. Your name, IP address, or other personal information will not be recorded.

If you have any questions concerning the research study, please contact the research team at: Mary.Niemczyk@asu.edu (Primary Investigator) or Kasey.stevenson@asu.edu (Co-Investigator). If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788. Please let me know if you wish to be part of the study.

Thank you in advance for your participation in this study.

Kasey Stevenson

APPENDIX B

DEMOGRAPHIC INFORMATION

Q2 - Have you previously completed high altitude chamber training?

#	Answer	%	Count
.	Yes	91.87%	113
2	No	8.13%	10
	Total	100%	123

Q3 - When did you last complete high altitude chamber training?

#	Answer	%	Count
1	0-6 months	17.12%	19
2	6-12 months	11.71%	13
3	Over 12 months	71.17%	79
	Total	100%	111

Q4 - What was your primary purpose for attending high altitude chamber training?

#	Answer	%	Count
1	Elective training	30.63%	34
2	Required by employer	45.95%	51
3	Academic credit	13.51%	15
4	WINGS credit	1.80%	2
5	Other	8.11%	9
	Total	100%	111

Q4 – Responses to ‘Other’

Military explosive decompression and recognition of hypoxia syndrome
Military
As a Navy Instructor at the Naval Aerospace Medical Institute, Pensacola
Pilot Training and for research
US Navy Aviator every 4 yrs
Military
Recurrent military training for high performance jet pilots
Military

Q5 - What is your highest pilot certificate held?

#	Answer	%	Count
1	Sport Pilot	0.00%	0
2	Private Pilot	10.81%	12
3	Commercial Pilot	16.22%	18
4	Certified Flight Instructor	11.71%	13
5	Airline Transport Pilot	45.95%	51
6	Other	6.31%	7
7	Not applicable	9.01%	10
	Total	100%	111

Q5 – Responses to ‘Other’

Professional Skydiving Instructor
millitary pilot
Former military carrier based jet pilot
A&P Licensa

Student Pilot

Q6 - What is your profession?

Director of Safety
Professional Skydive Instructor
Manager
Pilot
Pilot
Corporate Pilot
Pilot and trainer
Aerospace Engineer
Student
Pilot
Student
Pilot
Pilot
Corporate pilot
Retired Military and corporate pilot.
Airline Pilot
Airline pilot
Electrical Engineer
Aviation Ops Mgt
Aerospace Engineer
Senior Aviation Analyst
aviation safety consultant
Aircraft Dispatcher
Aviation Advisor

Airline pilot
Retired (Boeing)
Teacher
Investigator
Airline Safety Evaluator
Retired
Captain / G650 Fleet Technical Pilot
Retired FAA aviation safety inspector
Pilot
Professor
Engineer
Flight Test Engineer
Corporate pilot
Aerospace Engineer
retired A&P mechanic
Pilot
Flight Instructor
Pilot
Flight Test Engineer
Pilot
Pilot
Test Pilot
Retired GA Pilot
Student, I want to be an airline pilot
Airline Pilot / Mgr. Flt Ops Safety
Test Pilot
Loadmaster
Aviation consultant

Aerospace Engineer
Pilot
A&P Mechanic w/ IA
Naval Aviator on Carriers
Pilot
Flight Instructor
Pilot
Flight Test Engineer
Systems Engineer
Flight Test Engineer
Pilot
Instructor
aviation safety
Engineer
Flight Instructor
Airline pilot
Aerospace
Test Pilot
Pilot
Helicopter Pilot
Flight instructor
Propulsion Technician
Army
Pilot
Retired college professor
Coal Miner
Flight Instructor
Pilot and safety manager

Teacher
aeronautical engineer
Corporate Pilot
C-130 Loadmaster
Flight Surgeon
Aviation Safety
Engineer
Airline Pilot
Flight Engineer
Balloon Designer [Am I still anonymous ha, ha?!]
Pilot
Program Manager
USAF
Pilot
Student
Police Officer / Pilot
Air traffic control specialist
Pilot, Aviation Manager
Pilot
pilot
Student
Retired Airline Pilot
CFI Student / Pilot
UAL pilot
Pilot
Restaurant Server
Airline pilot
Manager in Oilfield Service Company

Q7 - What is your current student status?

#	Answer	%	Count
1	Full-time student	14.41%	16
2	Part-time student	1.80%	2
3	Not applicable	83.78%	93
	Total	100%	111

Q8 - What is your age?

Age:	Number of Respondents:	Age:	Number of Respondents:
19	1	54	3
20	2	55	6
21	4	56	2
22	8	57	1
23	4	58	3
24	3	59	5
25	1	60	2
27	1	61	3
28	1	62	2
29	1	63	5
30	2	64	3
31	3	65	2
32	2	66	2
33	1	68	1
34	1	69	2
35	4	70	2
37	1	72	2
39	1	73	1
41	1	74	2
47	1	75	1
48	1	76	1
50	4	84	1
52	3	88	1
53	1	over 60	1

Q9 - What is your gender?

#	Answer	%	Count
1	Male	91.82%	101
2	Female	8.18%	9
3	Prefer not to answer	0.00%	0
	Total	100%	110

APPENDIX C

ADDITIONAL T-TEST DATA

One-Sample Test

	Test Value = 3					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hypoxia affects pilots above 25,000 feet.	-3.351	109	.001	-.427	-.68	-.17
Current Federal Aviation Regulations are sufficient to prevent hypoxia.	-1.354	109	.178	-.164	-.40	.08
Classroom-based aviation physiology training is insufficient	-4.774	109	.000	-.536	-.76	-.31
The effects of hypoxia are not of concern below 14,000 feet.	12.289	109	.000	1.045	.88	1.21
It is important to know my symptoms of hypoxia.	-48.691	109	.000	-1.836	-1.91	-1.76
Prior to participating in HCT I would have recognized my symptoms	6.708	109	.000	.682	.48	.88
After participating in HCT I would recognize my symptoms of hypoxia	-22.928	109	.000	-1.436	-1.56	-1.31

I am a safer pilot, crewmember, or other support personnel	-32.994	109	.000	-1.691	-1.79	-1.59
HCT would be difficult to replicate in classroom-based training.	-35.092	109	.000	-1.736	-1.83	-1.64
HCT training presents an unnecessary risk	14.337	109	.000	1.082	.93	1.23
I would recommend HCT	-43.642	109	.000	-1.791	-1.87	-1.71
I would feel safer knowing the pilot/s had HCT	-25.550	109	.000	-1.536	-1.66	-1.42
All pilots should receive initial HCT	-11.088	109	.000	-1.027	-1.21	-.84
All pilots should receive recurrent HCT	-4.364	109	.000	-.427	-.62	-.23
HCT should remain elective training	.635	109	.527	.064	-.14	.26

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Hypoxia affects pilots above 25,000 feet.	110	2.57	1.337	.128
Current Federal Aviation Regulations are sufficient to prevent hypoxia.	110	2.84	1.267	.121
Classroom-based aviation physiology training is insufficient	110	2.46	1.178	.112
The effects of hypoxia are not of concern below 14,000 feet.	110	4.05	.892	.085
It is important to know my symptoms of hypoxia.	110	1.16	.396	.038
Prior to participating in HCT I would have recognized my symptoms.	110	3.68	1.066	.102
After participating in HCT I would recognize my symptoms of hypoxia.	110	1.56	.657	.063
I am a safer pilot, crewmember, or other support personnel	110	1.31	.538	.051
HCT would be difficult to replicate in classroom-based training.	110	1.26	.519	.049
HCT training presents an unnecessary risk	110	4.08	.791	.075
I would recommend HCT	110	1.21	.430	.041
I would feel safer knowing the pilot/s had HCT	110	1.46	.631	.060

All pilots should receive initial HCT	110	1.97	.972	.093
All pilots should receive recurrent HCT	110	2.57	1.027	.098
HCT should remain elective training	110	3.06	1.052	.100

APPENDIX D

SURVEY

Hypobaric Chamber Training Perceptions and Experience

Q1 Dear Participant,

I am a graduate student under the direction of Dr. Mary Niemczyk in the Aviation Programs of the Fulton Schools of Engineering at Arizona State University. I am conducting a research study to examine the perceptions and experience of individuals who have completed high altitude chamber training in a hypobaric chamber. The purpose of this study is to collect data to understand whether participants of high altitude chamber training perceive the training as a tool which increases the margin of safety for pilots through hypoxia awareness.

I am inviting your participation, which will involve completing a short 5-minute questionnaire with various questions related to your perceptions of hypoxia, hypoxia training, and your experience with high altitude chamber training. You have the right not to answer any question, and to stop participation at any time.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty. You must have previously completed hypoxia training at a high altitude (hypobaric) chamber to participate in the study. There are no foreseeable risks or discomforts to your participation.

There will be no compensation for time spent on this questionnaire. Although there is no direct benefit to you, possible benefits of your participation include greater awareness of hypoxia and its affects, and the potential for greater safety within the aviation industry as a result of improved physiological training and hypoxia awareness practices.

Your responses will be anonymous. The results of this study may be used in reports, presentations, or publications. Basic demographic questions including your age, gender, training history, and profession will be asked. Your name, IP address, or other personal information will not be recorded.

If you have any questions concerning the research study, please contact the research team at: Mary.Niemczyk@asu.edu (Primary Investigator) or Kasey.stevenson@asu.edu (Co-Investigator). If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.

Clicking 'agree' below indicates that I have read the description of the study and I agree to participate in the study.

O Agree

O Disagree

Q2 Have you previously completed high altitude chamber training?

O Yes

O No

Q3 When did you last complete high altitude chamber training?

O 0-6 months

O 6-12 months

O Over 12 months

Q4 What was your primary purpose for attending high altitude chamber training?

O Elective training

O Required by employer

O Academic credit

O WINGS credit

O Other ____

Q5 What is your highest pilot certificate held?

O Sport Pilot

O Private Pilot

O Commercial Pilot

O Certified Flight Instructor

O Airline Transport Pilot

O Other ____

O Not applicable

Q6 What is your profession?

____

Q7 What is your current student status?

O Full-time student

O Part-time student

O Not applicable

Q8 What is your age?

____

Q9 What is your gender?

- O Male
- O Female
- O Prefer not to answer

Q10 Hypoxia affects pilots most often when flying above 25,000 feet.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q11 Current Federal Aviation Regulations allowing pilots to fly with cabin altitudes up to 12,500 feet MSL, or up to 14,000 feet MSL for up to 30 minutes without supplemental oxygen are sufficient to prevent hypoxia.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q12 Classroom-based aviation physiology training provides insufficient knowledge for hypoxia recognition.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q13 It is important to know my own symptoms of hypoxia.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q14 The possible effects of hypoxia are not of concern to me below 14,000 feet.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q15 Prior to participating in high altitude chamber training, I am confident I would have recognized my symptoms of hypoxia, if they would have occurred.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q16 After participating in high altitude chamber training, I am confident I would recognize my symptoms of hypoxia, if they were to occur.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q17 I am a safer pilot, crewmember, or other support personnel for having attended high altitude chamber training.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q18 High altitude chamber training provided a training experience which would be difficult to replicate in solely classroom-based training.

O Strongly agree

O Agree

O Neither agree nor disagree

O Disagree

O Strongly disagree

Q19 High altitude chamber training presents an unnecessary risk for participants.

O Strongly agree

O Agree

O Neither agree nor disagree

O Disagree

O Strongly disagree

Q20 I would recommend high altitude chamber training to other pilots or interested individuals.

O Strongly agree

O Agree

O Neither agree nor disagree

O Disagree

O Strongly disagree

Q21 I would feel safer as a passenger knowing the pilot/s had undergone high altitude chamber training.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q22 All pilots should receive initial high altitude chamber training.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q23 All pilots should receive recurrent high altitude chamber training.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree

Q24 High altitude chamber training should remain elective training under Federal Aviation Regulations.

- O Strongly agree
- O Agree
- O Neither agree nor disagree
- O Disagree
- O Strongly disagree