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Air Consumption and Air Management in the Fire Service

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AIR CONSUMPTION AND AIR MANAGEMENT IN THE FIRE SERVICE

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DEDICATION

This thesis is dedicated to my wife Sarah and my children Morgan and Caleb for their unwavering support in pursuing my education. Also to my parents, Gary and Elaine Broderick without whom, my educational endeavors would have been impossible. Finally to Raymond Johnson, Jr. and Kevin Darnell without whose contributions, this thesis would have been impossible. Last but not least, to all of my brothers and sisters at my department and in the fire service around the world.

"From this day to the ending of the world,
But we in it shall be remembered-
We few, we happy few, we band of brothers;
For he today that sheds his blood with me
Shall be my brother"

– William Shakespeare's *Henry V*

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ABSTRACT

This research was undertaken in order to determine if there was a significant difference between various factors affecting air consumption rates and air management in the fire service. The purpose was to develop a better understanding of what had the most significant effect on air consumption rates in order to develop a point of focus so that fire departments could concentrate their efforts on an area of improvement that would give them the most return for their effort. An air management obstacle course was utilized to simulate work any firefighter could be reasonable expected to perform at a structure fire. All of the volunteer participants were members of the fire service in some capacity. In order to participate, the individual had to be a member of a career, part-time, or volunteer fire department. Measurements were taken of the air that was contained in their self-contained breathing apparatus prior to beginning the obstacle course and a second measurement was taken once the participant had completed the obstacle course. The two measurements were used to calculate air consumption rates in psi per minute and cubic feet per minute.

It was concluded that the sample size (59) of volunteer participants was too small to produce significant results in this type of study. Further research should be undertaken in order to gain a more in-depth understanding of what affects air consumption rates and air management in the fire service.

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CHAPTER I

INTRODUCTION

Throughout history, fires have been an integral part of life since man discovered the benefits of fire and how to turn it into a tool. Along with the benefits of this "tool," came the dangers associated with fire. As civilization grew, so did the danger posed by fire in the larger, settled areas of the world. In response to the dangers, the evolution of the firefighting profession began. As a result, there was a rise in the innovation of technology and protective equipment that would provide a measure of safety for those engaged in firefighting operations. One of those innovations was the development of respiratory protection devices that were designed to allow firefighters to enter smoke-filled environments to rescue people and to extinguish the fire while reducing the risk to the firefighters.

The purpose of this thesis is to examine factors that affect firefighters' air consumption rates and attempt to determine which factor can be focused on to provide departments with a method to improve rates among their personnel. This study will allow departments across the country to focus their time and effort on the most efficient factor that will allow them to gain the most from their investment in training and physical fitness. By exploring the results of this testing, it will provide departments with some insight into where they need to focus money and training efforts to provide their personnel with the information they need to manage better the air supply they take with them into hazardous atmospheres.

The first reported respiratory protection devices developed in the fire service were supposedly developed firefighters themselves. Popular firefighting folklore recounts the tales of firefighters growing long beards or mustaches to help them breathe when engaged in fire suppression operations. (http://lishfd.org/History/scba_history.htm) This theory explains why impressive mustaches can still be found in many firehouses today. The theory was that firefighters would dip their mustaches or beards in a pail of water and then clinch them in their teeth. It was said that breathing through the mouth would allow the wet whiskers to act as a filter which would allow the firefighter to breathe cleaner air.

Early attempts at creating breathing apparatus started in France and resulted in a unit that was worn on the head of the user, and consisted of an asbestos mask and a wire mask to filter the air. Around 1861, James Braidwood, the superintendent of the London Fire Brigade invented another type of hose mask that was revolutionary at the time. His apparatus consisted of a tube attached to the mask with the other end attached to an air pump which was mounted on the fire engine. A stout leather dress and hood were worn to protect the wearer from heat and flames and a powerful reflecting lantern was worn on the chest. A whistle was attached to the hood to provide a means of emergency communication for the firefighter. (http://lishfd.org/History/scba_history.htm) The first apparatus that resembled current day breathing apparatus came in 1863 when A. Lacour was granted a patent for his "improved respiring apparatus." The device consisted of an airtight bag made of two layers of canvas, separated by a lining of India rubber. The device was worn on the users back similar to current day SCBA, and the bag was filled with purified air by inflating with a pair of bellows. The device came in different sizes that corresponded to different duration from 10 to 30 minutes. This device was tested by various Fire Departments, including New York City, Brooklyn, and even the United States Navy. There were many other developments that came during this period, some were effective, and most were not. However, the development and evolution of firefighter respiratory protection devices were underway. (http://lishfd.org/History/scba_history.htm)

Today, with the advent of better personal protective equipment and SCBA, firefighters are able to enter a burning building and travel farther into the structure than ever before. This is resulting in firefighters getting trapped or running out of air if they do not monitor their air supply and exit the building before their air supply is exhausted. Fire fighters are the only workers in the workforce who are required to take their breathing air supply with them to the worksite. The supply is finite and must be treated in a manner that allows firefighters to enter the work area, perform their tasks, and exit the work area before running out of air. In order to accomplish this, they must be trained in the use of their SCBA and its functions and limitations. To address this issue, the National Fire Protection Association (NFPA) created NFPA 1404: *Standard for Fire Service Respiratory Protection Training* which mandates that every department have an air management policy in place. (NFPA, 2013) The Georgetown Fire Department in Georgetown, Kentucky addresses this issue by having all members participate in an Air Management training session twice per year. The training consists of the completion of an air management obstacle course in which the firefighters complete a series of tasks while breathing air from their SCBA. The tasks consist of simple fireground related tasks that all firefighters can reasonably be expected to perform on the scene of a structure fire.

The training evolution is timed and the results are put into a spreadsheet that calculates the air consumption rates for each firefighter and whether they improve on their previous consumption rates or decrease in their previous consumption rates. This is used to meet the requirements of an air management program as well as to assess the physical abilities of the firefighters of the department on a bi-annual basis.

The purpose of this thesis will be to conduct a study of air management and the results to determine which factor most affects a firefighter's ability to extend the lifespan of a cylinder of breathing air. This will allow a focus on the aspect that most influences air consumption rates so that firefighters can be better trained to make the most of the air supply they carry with them on their backs. A series of volunteers will be asked to complete the air management course and their results will be analyzed for consistencies and discrepancies to determine where firefighters should be focusing their efforts. The factors that will be studied for their effects on air consumption rates are physical fitness, experience, and gender. The determining factors for what consists of a physically fit firefighter and what consists of an experienced firefighter will be addressed in the Methodology section. The volunteers will be sought from career, part-time, and volunteer fire departments in central Kentucky. The requirement for participating in the study will be that a person has to demonstrate proof that they are affiliated with a career, part-time, or volunteer fire department in Kentucky or elsewhere. All other conditions for participation will be addressed in the methodology section.

CHAPTER II

LITERATURE REVIEW

"On March 14, 2001, 40-year old Bret Tarver, a firefighter-paramedic in the Phoenix Fire Department, died in the line of duty while battling a fire at the Southwest Supermarket. Bret Tarver became separated from his crew, ran out of air in his SCBA, took off his facepiece, and breathed the toxic and poisonous gases that are present in smoke. Bret Tarver died of carbon monoxide poisoning." (Gaglinano, Phillips, Jose, & Bernocco, 2008) The Southwest Supermarket was a 20,132 square foot commercial building that can be found in practically any firefighters' response area. The origin of the fire was determined to be in a pile of cardboard outside the building and was determined to be arson because no accidental causes were discovered. Engine 14 was the company to which Tarver was assigned, was fighting fire on a handline in the produce area of the store when they began to experience intense heat and thick, black smoke down to the floor level. At this point, Tarver told his officer that he was low on air. The issue is that the area where the crew was operating was located about two-thirds of the way deep into the structure; a long way to be traveling in order to exit a building while low on air. Tarver and another firefighter became separated from the handline after falling over some debris. The officer of Engine 14 became disoriented but was put back on the handline and sent toward the exit by the officer from Engine 3. Tarver and the other firefighter unknowingly moved further into the structure. The Engine 14 officer's low air alarm activated and he ran out of air near the front door of the building. (Gaglinano, Phillips, Jose, & Bernocco, 2008) Once Tarver was located, many crews worked to remove him from the structure. They were hindered by his size, he was 6 feet, 4 inches tall and weighed over 300 pounds with his gear on. Approximately 19 minutes elapsed between the time he was found and the time he was removed from the building. The Chief of the Phoenix Fire Department Alan Brunacini stated that "Air management must become a major fireground factor in determining, managing, and maintaining the overall strategic mode (offensive vs. defensive). (Gaglinano, Phillips, Jose, & Bernocco, 2008)

Following the Bret Tarver Line of Duty Death, the Phoenix Fire Department and the National Institute for Occupational Safety and Health (NIOSH) recognized that firefighters had an inherent need to understand the parameters of air management and to be trained in air management. (Gaglinano, Phillips, Jose, & Bernocco, 2008) NIOSH investigators determined that depending on firefighters' individual air consumption rates and the amount of time required to exit the structure, the low-air alarm ("Vibra-lert" on Scott air packs) might not activate in time to provide adequate time to exit a structure. Instead, firefighters should learn to monitor and manage their air. Since scuba divers must monitor their air frequently while submerged, it is common sense that firefighters might want to do the same thing when engaged in firefighting operations in the air supply for both firefighters and scuba divers is carried in a finite supply on the users back. The Phoenix Fire Department learned from the death of Bret Tarver and implemented a hands-on training program to address air management and became the first big city fire department to adopt an air management program. (Gaglinano, Phillips, Jose, & Bernocco, 2008)

The National Fire Protection Association has developed a standard that contains the minimum requirements for a respiratory protection program. This includes safety procedures for those who are expected to be involved in fire suppression, rescue, and related activities in a toxic, contaminated, or oxygen-deficient atmosphere or environment. (NFPA, 2013) The standard is known as NFPA 1404: *Standard for Fire Service Respiratory Protection Training* and includes provisions that shall provide members with annual training over a variety of subjects. Those include, but are not limited to: Donning and doffing (Putting on, and taking off equipment) respiratory protection equipment, uses and limitations of the equipment, consequences of an improper fit or poor maintenance which impacts the protection provided, how to perform seal checks, how to recognize medical signs and symptoms that can impact use of respirators, how to inspect respirators before use, procedures for maintenance and storage, individual limitations of members who could be required to use the respirators, and approved decontamination and disposal procedures for respiratory protection equipment. (NFPA, 2013)

The National Fire Protection Association's *Standard on Fire Service Respiratory Protection Training* also specifically lays out the requirements of an air management respiratory protection training component. The standard also requires that a respiratory protection program be established in accordance with NFPA 1500: *Standard on Fire Department Occupational Safety and Health Program.* The standard also requires that a department (Authority Having Jurisdiction or AHJ) "shall establish and enforce written standard operating procedures for training in the use of respiratory protection equipment that shall include an individual air management program". (NFPA, 2013) The standard requires that "the individual air management program shall be designed to develop the ability of an individual to manage his or her air consumption as part of a team during a work period". (NFPA, 2013) It also dictates that the program SHALL include three components: "(1) The individual shall exit from an IDLH atmosphere before consumption of reserve air supply begins; (2) The individual shall recognize that the low-air alarm notification indicates that the member is consuming the reserve air supply; and (3) The individual and the team shall take immediate action upon activation of the reserve air alarm and shall follow their department's standard operating procedures/standard operating guidelines." (NFPA, 2013)

A review of a number of Line of Duty Death reports from the National Institute of Occupational Safety and Health indicates several high-profile incidents where air was referenced in the report. Focusing on air management was cited as a way to minimize the risk of similar occurrences. These incidents included the Worcester Cold Storage fire, the Southwest Supermarket fire (Bret Tarver), along with several one and two family residential dwelling fires.

On December 3, 1999, six career firefighters died after becoming lost in a six-floor, maze-like, cold storage and warehouse building while searching for two homeless people and fire extension. Two firefighters initially became disoriented and became lost. Four more firefighters became disoriented and lost during search and rescue operations for the first two firefighters. The Incident Commander eventually pulled all other firefighters from the building when the situation became so severe that he could not justify sending more firefighters in to look for the lost men. (NIOSH, Six Career Firefighters Killed in Cold-Storage and Warehouse Building Fire-Massachusetts Report # 99F-47, 2000)

On March 14, 2001 a career firefighter (Bret Tarver) was killed in the Southwest Supermarket fire in Phoenix which resulted in the actions taken that were discussed at the beginning of this literature review. The result of this fire was the first implemented "air management" program that was widely reviewed in the fire service. (NIOSH, Supermarket Fire Claims the Life of One Career Firefighter and Critically Injures Another Career Firefighter - Arizona Report # F2001-13, 2002)

On July 24, 2010 a 40 year old male career Lieutenant and a 49 year old male career firefighter were found unresponsive at a residential structure fire after running out of air. They had been tasked with conducting a primary search for civilians and fire extension on the third floor of a multi-family residential structure. They entered the building after the fire had been extinguished on the 2nd floor. While pulling walls and ceiling on the 3rd floor smoke and heat conditions changed rapidly. Both victims were removed by rapid intervention teams and pronounced dead at local hospitals. (NIOSH, A Career Lieutenant and a Career Firefighter Found Unresponsive at a Residential Structure Fire - Connecticut Report#F2010-18, 2011)

On May 8, 2013 a 29 year old male career probationary firefighter died after running out of air and being trapped by a roof collapse at a commercial strip mall fire. He was part of a hose team that had stretched a hoseline deep into the structure under high heat and heavy smoke conditions. He became separated from his crew and ran out of air. A rapid-intervention team was activated but was unable to locate him before a flashover occurred and the roof collapsed. (NIOSH, Career Probationary Firefighter Runs Out of Air and Dies in Commercial Structure Fire - Michigan Report #F2013-14, 2016)

On October 7, 2014 a male career firefighter died while conducting interior fire-fighting operations in a two-story residential apartment fire. The officer in charge had the firefighter "pencil" the ceiling (a technique used when conducting flashover/live fire training when an instructor wants to lower the fire intensity without extinguishing it). Minutes later, the firefighter's vibra-lert (low air alarm) activated and the officer told him to exit the building. The firefighter was found near the door with his foot caught in a piece of furniture. He was brought out of the structure and transported to a hospital where he was pronounced dead. (NIOSH, Career Firefighter Dies From an Out-of-Air Emergency in an Apartment Building Fire - Connecticut Report#F2014-19, 2017)

On July 9, 2014 a male career firefighter died while conducting interior operations in a two-story residential structure fire. The officer inside at this fire heard one of his firefighters say he was getting "hot, low on air, and, 'Let's go get flashlights.'"The crew was backing down the stairs when the officer realized a firefighter was missing. The officer went back to the second floor to find the missing firefighter but his low-air alarm began to go off and he had to back out. The down firefighter was found just inside the double doors that led to the second story back deck of the residence and removed from the structure down a ladder by another crew. (NIOSH, Career Firefighter Dies in Heavy Smoke on Second Floor of a Residential Structure - Texas Report #F2014-15, 2016)

These twelve firefighter line of duty deaths were all found to have a contributing factor of running out of air or not observing air management techniques. The experience levels of the firefighters range from more than thirty years of experience to a probationary firefighter with less than one year of experience. The problem of air management runs throughout the fire service and encompasses all experience level and ages, and it does not matter whether the department is a career department or volunteer department. Therefore, it is necessary to conduct this study in order to determine which aspect a department should focus its training on in order to gain the most benefit from the air supply firefighters carry into a hostile environment with them.

Several issues have been discussed regarding how firefighters can maximize their air usage. Foremost among these is physical fitness and training with the equipment they will be using. No small number of articles and research has been done regarding the physical fitness of firefighters, because in 2014 (the most recent year a FEMA report is available) sixty-one firefighters died as the result of stress or overexertion. Fifty-nine of those deaths were heart attacks, and two of them were diagnosed as strokes. (USFA, 2015) This is over half of the ninety-one firefighters who died in the line of duty in 2014 and serves as sufficient evidence for increased physical fitness training in the fire service.

"Amazingly, firefighters run into burning buildings every day with little hesitation or thought that, without their self-contained breathing apparatus (SCBA), death would be likely. Huge improvements in respiratory protection over a century – whiskers saturated with water used as filters, filter masks, the chemical rebreather, the negative-pressure SCBA, the present positive-pressure units – all have contributed to a safer and more productive working environment. (Davis, 2016) SCBA does have limitations however. It is the single heaviest piece of Personal Protective Equipment a firefighter uses. In addition to his/her turnout or bunker gear along with the additional equipment each firefighter carries, a firefighter may weigh 50 plus pounds more than his/her normal body weight and that is before the gear is soaked with water or sweat from firefighting operations or dragging a heavy hose around. Physical size also has much to do with air consumption rates. Larger firefighters carry a disproportionate smaller percentage of external weight in comparison to smaller firefighters. This should be looked at in terms of power to weight ratio. However, the larger the mass, the more oxygen it requires to operate. This is the reason two firefighters of different body sizes will have a much different rate of consumption when breathing from a 30-minute cylinder while at rest. Nerves and adrenaline can also have a major impact on the rate of air consumption when engaged in firefighting operations. Dr. Davis offers four methods to increase air consumption rates; the first is to become more physically fit since fit individuals are capable of getting more work done per unit/volume of oxygen; the second is to practice breathing control which will extract more oxygen per breath by slowing down the breathing rate; Avoid resorting to the SCBA by-pass which will allow air to free-flow and waste it; and Exhale against a slight overpressure which will increase the partial pressures in the pulmonary tree and force oxygen across the alveoli in the lungs from the pressure gradient. Figure 1: Fitness Classifications and Work Performance in the Appendix shows a graphic story as to how body composition can have a severe impact on performance which underscores the importance of lean (fat-free) muscle mass versus more adipose (fat) tissue. Simply put, during the study that resulted in the table, the firefighters in the “poor” category were carrying the equivalent of an extra SCBA under their skin in the form of adipose tissue. “It’s a simple matter of physics. All mass takes energy to move, whether it’s strapped to your back or part of your body. And, because fat is metabolically inactive, it makes no contribution to the creation of energy but actually costs you in your ability to perform”. (Davis, 2016)

Firefighters experience many stressors while performing their jobs. Nearly 80,000 are injured each year and approximately 100 firefighters lose their lives in the line of duty each year. Toxic fumes, dangerous products of combustion, high radiant heat loads, and chaotic work environments all lead to a variety of dangers. The “leading cause of death among firefighters is a sudden cardiac event, accounting for nearly 45% of duty deaths”. (Smith, 2011) According to the research cited in the article, “when expressed relative to the type of call they are responding to, approximately 23 to 25 firefighters are injured per 1,000 fires whereas only 0.6 to 0.7 injuries occur per 1,000 non-fire emergencies. Firefighting also results in approximately 5.7 firefighter fatalities per 100,000 structure fires. A retrospective study performed between 1995 and 2004 revealed that 1,006 firefighters had died in the line of duty during that period. Approximately 45% of those fatalities were the result of cardiovascular events”. (Smith, 2011) Smith also cites the detrimental effects of excess body fat and makes the statement that “firefighters also should possess an appropriate body composition.” Smith also indicates that studies have shown that “estimated oxygen consumption associated with firefighting ranges between a VO_{2max} of 33.6 and 49.0”. Based on research she also cites a recommendation from the NFPA that states firefighters should have a minimal aerobic VO_{2max} of 42 (metabolic equivalent of task (MET) score, 12) While the author’s work is mainly concerned with the physical fitness of firefighters, and the cardiovascular health of the work force, it applies to this thesis research because a healthier firefighter makes more efficient usage of oxygen and would have a higher VO_{2max} resulting in an increased ability to perform work over a longer period of time by making better use of the air supply in his or her SCBA.

“Firefighters represent a unique occupational group in that their job puts them in harm’s way on a daily basis in order to protect the safety and well-being of others. Yet, the leading cause of mortality among this occupational group is not injury but sudden cardiac death.” (Donovan, et al., 2009) The article cites the increasing volume of literature that indicates that low cardiorespiratory fitness is a major modifiable risk factor for several chronic diseases and premature mortality. Metabolic Syndrome is the “clustering of several cardiovascular disease risk factors (Donovan, et al., 2009) and the effects of this syndrome on this occupational group. While previous work had focused on hypertension, dyslipidemia, and obesity, less work has been done on Metabolic Syndrome. This study was conducted in order to determine and document the levels of cardio respiratory fitness and the metabolic syndrome, as well as to determine if there is a relationship between these variables, in firefighters. Key points determined as a result of this study include:” Of the 214 firefighters evaluated, 15% met diagnostic criteria for the metabolic syndrome and 25% had an estimated cardio respiratory fitness level below that deemed necessary for safe and effective job performance. Increased levels of cardio respiratory fitness in firefighters were associated with a decreased number of metabolic abnormalities identified in this study. All fire departments should consider incorporating annual fitness evaluations, exercise guidance and minimum fitness standards as part of a comprehensive cardiovascular disease risk reduction strategy in this occupational group.” (Donovan, et al., 2009)

“Deaths from coronary heart disease were associated with suppressing a fire (32.1% of all such deaths), responding to an alarm (13.4%), returning from an alarm (17.4%), engaging in physical training (12.5%), responding to non-fire emergencies

(9.4%), and performing non-emergency duties (15.4%). As compared with the odds of death from coronary heart disease during nonemergency duties, the odds were 12.1 to 136 times as high during fire suppression, 2.8 to 14.1 times as high during alarm response, 2.2 to 10.5 times as high during alarm return, and 2.9 to 6.6 times as high during physical training." (Kales, Soteriades, Christophi, & and Christiani, 2007) Fire suppression was associated with the highest risk, and ironically, this is the time during which firefighters are wearing their self-contained breathing apparatus and full personal protective equipment.

"Intuitively, high levels of physical fitness will aid firefighters to perform tasks such as pulling fire hose, carrying equipment up and down stairs or ladders, forcibly entering or ventilating structures, and carrying victims to safety, and higher levels of fitness have been correlated with decreased risk of injury. However, little research has been published that examines the correlation between a wide range of physical fitness measures and job performance in this population." (Rhea, Alvar, & Gray, 2004) The authors of this article explore the relationship between fitness and job performance. In order to do so, they recruited professional firefighters to perform a battery of fitness and job-related performance testing. Body composition was measured, and four separate job performance tasks were performed as quickly as possible and timed for performance score. All tests were performed in turnout clothing, including boots, pants, coat, and helmet while wearing a standard self-contained breathing apparatus tank without the face mask attached. The findings of this study included that firefighters must maintain high levels of muscular strength, muscular endurance, and cardiovascular and anaerobic exercise. All areas of physical fitness should be addressed and not just focusing primarily on cardiovascular endurance and anaerobic endurance such as has been done in the past. (Rhea, Alvar, & Gray, 2004)

Another factor that comes into play with improving air management in the fire service is experience and training. These two topics go hand in hand because with training comes more experience in utilizing the life-saving equipment. In order to improve air management, there has to be a constant awareness of a firefighter's air supply while the firefighter is engaged in fire suppression activities. While at depth, scuba divers constantly monitor their air supply so it should be relatively easy to perform the same air supply checks while engaged in fire fighting operations, especially since there is a heads-up display (HUD) located on the face masks of the self-contained breathing apparatus. For instance, on the Scott air packs that were used for the data collection portion of this research, the heads up display contains four lights. A full cylinder is indicated by two glowing green lights. Three-quarters cylinder is indicated by a single glowing green light. Half a cylinder is indicated by a yellow light flashing once per second. The one-third cylinder end of service time light is red and flashes at 10 times per second. When this light is flashing, a firefighter MUST leave the hazardous atmosphere immediately. (https://www.scottsafety.com/en/us/DocumentandMedia1/Engineering/UserManuals/UserManuals/595279-01_B.pdf) It is realistic to think that a firefighter could perform a rapid air check on his or her pressure gauge whenever the status of these lights change on the HUD. It would simply take training as part of a comprehensive air management program in order to accomplish this.

"Close calls with running out of air can happen anywhere, anytime, and to anyone. In March 2001, while fighting a second alarm structure fire, an East Hartford (Connecticut) Fire Department Lieutenant ran out of air while in an IDLH atmosphere". (Perez, 2009) The firefighter had continued working after the activation of his low air alarm at 25% of his air supply remaining. This did not leave him enough time to adequately evacuate the building and he exhausted his air supply prior to exiting the IDLH environment. The author of this project writes that it is not "uncommon to hear low air alarms sounding while firefighters are still working in IDLH atmospheres." (Perez, 2009) According to his literature review, Perez notes that "incidents of firefighters mismanaging air while in IDLH atmospheres continues due to the lack of adoption of appropriate individual air management programs" (Perez, 2009) and that the "third leading cause of non-traumatic deaths on the fire ground is asphyxiation, typically caused by running out of air or getting lost and disoriented" (Perez, 2009). Of specific interest that should be noted in this research project is the answer of one of the respondents to the questionnaire sent out as part of this research project. A Fire Chief in Kansas responded that he asked his firefighters what their SCBA training told them about when it was time to leave a building at a fire. Nearly 100% of the time, they responded that they were taught to leave the building when the low air alarm sounded. Waiting for the low air alarm may put firefighters at the point of no return, which is referenced in NFPA 1404. It symbolizes the point beyond which a firefighter is unable to return from inside an IDLH environment.

"Firefighters in the United States are dying at an alarming rate and the third leading cause of these deaths is running out of air in dangerous environments. Routinely, firefighters wait until their low-air alarm activates before they leave a dangerous environment" (Quick, 2011) According to the author of this Executive Fire Officer Program applied research project, the mean air usage for a firefighter using a 45 minute cylinder was just over 22 minutes while performing simulated firefighting tasks. The purpose of this applied research project was to establish an air management Standard Operating Procedure for the author's fire department and implement the guideline. "Because 'managing' air is a new concept for most of the fire rescue departments, including OCFRD, it will take time, experience, practice, and training to become air management proficient. The only way to do this is by knowing how much air you have before you go into the Immediately Dangerous to Life and Health (IDLH) environment, manage what you have while inside the hazardous atmosphere, and exit the situation before you low air alarm activated, thus following the 'Rule of Air Management'". (Quick, 2011)

In his applied research project for the National Fire Academy's Executive Fire Officer Program, Willard Scott Justice elected to conduct research into identifying strategies to improve air management during emergency operations to increase the probability that members of his department would exit an Immediately Dangerous to Life and Health atmosphere prior to activation of their self-contained breathing apparatus low-air alarm activation. As in many departments, the author of this research project states that it was not uncommon to hear low-air alarm activations on scenes where his department was working. In some cases, members would often work into their emergency reserves without properly managing their air supply. Many of them would rely on the low-air alarm to tell them when to exit the structure. This becomes problematic when firefighters encounter unexpected delays or become disoriented when trying to exit the hazardous area. (Justice, 2013) He states that this tactic works more often than not in the 1,500 to 2,000 square foot residential structures his department typically responds to. Because exits are typically close by, members continue to rely on their low-air alarm to tell them when to exit due to short travel distances to exits. As seen in previously cited literature, this is a fallacy that is proven untrue time and time again due to firefighters being killed when they run out of air in one and two family residential structures. This tactic becomes a major issue in commercial structures where travel distances are much greater if an emergency exit from the hazardous atmosphere is required. The major way to improve air management is to center change on a behavioral shift in which the discipline of air management is achieved through training and policy changes. (Justice, 2013)

A third aspect of this study centered on the difference in air consumption between male and female firefighters. A study done by Sara Jahnke, Carlos Poston, Keith Haddock, Nattinee Jitnarin, Melissa Hyder, and Cheryl Horvath centered on the aspects of the health of female firefighters. When compared to male firefighters (79.5% career and 78.4% volunteer overweight/obese Body Mass Index greater than 25), females had a more favorable body composition at 33.4% for career female firefighters and 46.2% for volunteer female firefighters. Females also had a smaller waist measurement than their male counterparts. They also tended to demonstrate high rates of physical fitness with regard to strength and flexibility but the rate of women meeting a 12 Metabolic Equivalent of Task (MET) was lower than that of male firefighters. Alcohol and tobacco use by female firefighters was more in line with those of their male counterparts. (Janke,

2012) The general findings of the study are that the health of women in the fire service is a generally healthy occupational workforce and more studies should be done to understand the health status and concerns of women in the fire service. (Janke, 2012)

CHAPTER III

METHODS

The method by which the study will be conducted will consist of two phases. The first phase will be the data collection phase. In this phase volunteers will complete an air management obstacle course. The second phase will consist of the analysis phase in which the data will be analyzed for consistencies and/or discrepancies. This will help identify which factor has the most influence in improving air consumption rates. This will also allow fire departments to manage their air management programs and focus their efforts on specific traits to maximize their time and effort in improving the ability of firefighters to effectively and efficiently manage their air supply.

The volunteer participants consisted of career and volunteer firefighters Experience levels ranged from 1 year to 28 years of service in the fire service and could encompass an individual's time spent as a combination of career, part-time, or volunteer firefighter service. The variables for the study consisted of whether a firefighter was an experienced or inexperienced firefighter, a physically active or physically inactive firefighter, and whether the participant was male or female.

In order to make the experienced determination, the descriptive statistics were run using Microsoft Excel using data taken from the participant questionnaire and the median years of service was used as a dividing point for this category. The median for this study was 10 years. There were 29 inexperienced volunteers and 30 experienced volunteers who participated in this study. The American Heart Association Standards for Physical Activity in Adults was used. The American Heart Association recommends that for

"overall cardiovascular health", a person should engage in at least 30 minutes of moderate-intensity aerobic activity at least 5 days per week for a total of 150 minutes per week OR at least 25 minutes of vigorous aerobic activity at least 3 days per week for a total of 75 minutes AND moderate-to-high-intensity muscle strengthening activity at least 2 days per week.
(http://www.heart.org/HEARTORG/HealthyLiving/PhysicalActivity/FitnessBasics/American-Heart-Association-Recommendations-for-Physical-Activity-in-Adults_UCM_307976_Article.jsp#.WLx3ok0o6M8)

The volunteers were required to self-report data on this category on the questionnaire they filled out before taking their turn on the air management obstacle course. There were 21 active and 38 inactive volunteers who participated in this study. There were a total of 56 males and 3 females who volunteered to participate in this study.

The secondary variables that were assessed were based on data taken from the questionnaire and during the obstacle course. These consisted of whether the volunteer was over or under the age of 30, whether the participant was a smoker or non-smoker, whether the participant was career or volunteer, and whether the participant was carrying gear that weighed in excess of 33% of his or her normal body weight or not. There were 28 participants under the age of 30 and 31 participants over the age of 30. There were 39 non-smokers, seven smokers, and 13 participants where a determination of smoking status could not be made. There were 52 career firefighters and seven volunteer firefighters who participated in this study. There were 36 firefighters who were not considered to be carrying heavy gear (> 33%), and there were 23 firefighters who were carrying a gear weight of greater than 33% of their body weight. This data was entered into the data collection forms from weight measurements taken from the volunteers who were first weighed in their bare feet (with socks on) and clothing. The second weight measurement was taken once they had donned their personal protective equipment just prior to beginning the air management obstacle course.

Air Management Obstacle Course

The Air Management Obstacle Course consists of several tasks that must be completed to complete the course. Each evolution is timed as well as maintaining an overall time that the user is on the course and that the user is actually breathing air from their SCBA. The level of air contained in the SCBA cylinder will be checked on the Georgetown Fire Department's air filling station (cascade), monitored on the Scott Safety SEMS II accountability software, and the cylinders will be weighed on precise scales prior to beginning the obstacle course. If at any time the user's air level reaches 2/3 full (3000 psi), the participant will immediately proceed to the exit search evolution.

The first evolution consists of the participant donning or putting on their full ensemble of personal protective equipment including their SCBA to the point at which they are breathing air from the apparatus. A piece of waxed paper will then be placed over the SCBA facepiece to obscure the vision of the participant. The participant will then crawl around the apparatus bay of a Georgetown Fire Station which will simulate a left-hand search pattern used to search a structure. Once complete, the wax paper will be removed, and the participant will move to the next evolution.

The participant will now be required to use the Keiser sled apparatus in which a mallet will be used to drive a beam the length of a metal tray which simulates the chopping action used when cutting a hole with an axe. The participant will then proceed to the "hose pull" evolution which consists of pulling a length of rope attached to a weighted sled across the apparatus bay. This simulates pulling a full fire hose on the fire ground.

The next evolution is the "ceiling pull" evolution which consists of pulling a weighted apparatus attached to a pike pole to simulate the pulling of the ceiling during a structure fire to find the hidden fire. The participant will stay on this evolution for a maximum of two (2) minutes or if their cylinder reaches 2/3 (3000 psi) full. If they are still above this level, they will proceed to the Stair Mill which simulates climbing stairs. They will remain on this evolution until 2/3 (3000 psi) cylinder remains. The final evolution is the exit evolution or a right-hand search pattern to simulate the exiting of a structure.

Once the evolution is complete, the participant has completed the obstacle course. Once the participant is finished, the cylinder will be checked on the SEMS II accountability software prior to shutting the pack off to ascertain the level of air in the cylinder, the cylinder will be placed back on the fill station (cascade) to measure the air level, and then the cylinders will be weighed on the scales. This information will be provided to the participant if they wish to have a copy of their results.

Data Analysis

The data collected will be input into a spreadsheet which will calculate an air consumption rate in psi per minute and cubic feet per minute for each participant. Once this data is entered into the sheet, a comparative analysis will be done to compute means, and standard deviation, comparison scores between the groups, and two-tailed T-tests will be used determine significant differences in the results.

CHAPTER IV

RESULTS

Design and Sample

The data collection process was completed over a period of four days and consisted of fifty-nine volunteers who participated in this study. Recruiting efforts for the study consisted of advertising on social media for participant volunteers, word of mouth, and phone calls made to friends in other departments. Before beginning the air management obstacle course, participants were asked to fill out a questionnaire that asked several questions about the participant. These questions consisted of how many years of experience they had in the fire service, what type of department they were part of (career, volunteer, or part-time), their workout routines, and their gender. The participants were required to wear the full complement of personal protective equipment which consisted of bunker boots, turnout pants, turnout coat, protective hood, helmet, gloves, and self-contained breathing apparatus with face piece (SCBA and face pieces were provided at the test site so that all participants were using identical equipment)

Measures

Demographic Characteristics. Survey items included gender, age (30 or younger versus over 30), years of service, a self-reported indicator of whether the participant was physically active, career versus volunteer firefighter status, and current smoking status. Body weight was measured both with and without gear; gear consisted of bunker boots, turnout pants with liners, turnout coats with liners, protective hoods, gloves, helmets, and self-contained breathing apparatus with face pieces. A measurement of gear weight was calculated from the difference in these two weight measurements; participants whose gear added more than 33% of their normal body weight were identified from these measurements.

Cascade psi/min and cubic feet per minute. The process for measuring the amount of air in the cylinders consisted of three phases. The first phase was a measurement taken from the cascade air filling station at the Georgetown Fire Department that was visually checked on the filling station pressure gauges. This measurement was repeated when the volunteer had finished the course to obtain a second measurement from which a determination was made of how much air the volunteer had used on the course.

Formula to convert to Cubic Feet used when measuring cylinders on cascade system

65 cubic feet in full cylinder

4500 psi in full cylinder

$65\ ft^3/4500\ psi = 0.014444\ ft^3/psi$

$FT^3 = PSI \times 0.014444$

Weight psi/min and cubic feet per minute. The second phase consisted of weighing the cylinders before each person starting the course to obtain a weight measurement of the full cylinder. When the volunteer finished the obstacle course, a second weight measurement was taken to determine how much air had been used on the course. The measurement was then calculated in a formula to calculate the psi per minute and cubic feet per minute.

Formula to convert to PSI used when weighing cylinders

9.6 = Weight of empty cylinder

5 lb = weight of air in full cylinder

4500 psi = psi of air in full cylinder

5lbs /4500 psi = 0.001111 lb/psi

W = Weight of cylinder when measured on scales

<u>PSI = (W-9.6)/0.001111</u>

<u>Formula to convert to Cubic Feet used when weighing cylinders</u>

65 cubic feet in full cylinder

4500 psi in full cylinder

65 ft^3/4500 psi = 0.014444 ft^3/psi

<u>FT^3 = PSI x 0.014444</u>

SEMS II psi/min and cubic feet/min. The final phase consisted of using the Scott Electronic Management System (SEMS II) software package from Scott Health & Safety. The software is installed on a computer base station which is attached to a transponder that sends and receives a Bluetooth signal from Scott self-contained breathing apparatus air packs that are activated in the area near the transponder. This system allows the incident commander to monitor the air supply of each firefighter in the hazardous environment as well as send and receive signals from the air pack such as transmitting or receiving Personal Alert Safety System (PASS) signals that convey information back and forth between the firefighter and the incident commander. These signals can consist of individual or mass evacuation signals or emergency signals from firefighters who are in trouble inside the structure. It can also be used by the incident commander as an accountability system. This software allows for real-time tracking of the air supply of firefighters and was used in this study. (Scott Health & Safety, 2009) The SEMS II software package is most likely the most accurate of the three measuring procedures due to the fact that it removes the possibility of human error in taking the measurements.

Formula to convert to Cubic Feet used when weighing cylinders

65 cubic feet in full cylinder

4500 psi in full cylinder

$65\ ft^3/4500\ psi = 0.014444\ ft^3/psi$

$FT^3 = PSI \times 0.014444$

Analytical Strategy

Data were analyzed using descriptive statistics, including means and standard deviations or frequency distributions. The distributions of all air consumption measures were right-skewed; Mann-Whitney U Tests were used to compare median values between different participant groups. Data analysis was performed using SAS 9.3 for Windows (SAS Institute, Inc., Cary, NC, USA); a significance level of 0.05 was used throughout.

A majority of the participants were male (95%) career (88%) firefighters. There were thirty-one (31) participants over the age of thirty (53%) and twenty-eight (28) participants under the age of 30 (47%). Experience levels ranged from 1 to 28 years in the fire service and could encompass an individual's time spent as a combination of career, part-time, or volunteer firefighter; the mean years of service was 9.76 (SD=7.2215). A majority of the participants had more than five years of service (63%); however, only 37% had more than ten years of service. Of the participants, 21 (36%) self-reported as physically active while 38 (64%) identified as inactive. There were 52 (88%) career firefighters and 7 (12%) volunteer firefighters who participated in the study. There were 39 (66%) non-smokers, 7 (12%) smokers, and 13 (22%) participants where a determination of smoking status could not be made. There were 36 (61%) of participants who were identified as not carrying heavy gear (>33% of normal body weight) and there were 23 (39%) of the participants who were carrying a gear weight of greater than 33% of their body weight.

Neither experience with an air pack nor self-reported physical activity had a statistically significant effect on air management. However, participants with prior experience with an air pack reported higher air consumption rates, on average for both psi per minute and cubic feet per minute. (Table 4.1) Similarly, volunteers that self-reported as physically active, reported higher air consumption rates, on average, for psi per minute and cubic feet per minute.

Table 4.1 Air Consumption Rates by Demographic Characteristics (N=59)

	Cascade		Weight		SEMS II	
Variable	**PSI/Min**	**Ft^3/Min**	**PSI/Min**	**Ft^3/Min**	**PSI/Min**	**Ft^3/Min**
[illegible]						
Yes	275.08(46.7	3.97(0.785	199.39(32.9	2.88(0.475	268.59(40.8	3.88(0.590
No	268.65(51.7	3.88(0.747	190.45(37.2	2.75(0.538	260.16(48.6	3.76(0.702
Phys.						
Yes	273.82(56.7	3.95(0.820	196.98(37.5	2.84(0.543	268.39(52.4	3.88(0.757
No	270.87(44.7	3.91(0.647	193.90(34.1	2.79(0.493	262.27(40.3	3.79(0.583
Gender						
Male	273.82(49.2	3.95(0.711	196.53(35.1	2.84(0.508	266.55(44.8	3.85(0.648
Female	236.51(26.3	3.41(0.381	166.31(20.3	2.40(0.293	225.25(9.97)	3.25(0.144
Age > 30						
Yes	270.72(45.4	3.91(0.656	195.85(33.0	2.83(0.478	265.05(40.1	3.83(0.579
No	273.26(53.3	3.95(0.770	194.05(37.7	2.80(0.545	263.78(49.9	3.81(0.721
Smoker						
Yes	267.47(37.2	3.86(0.538	194.10(24.1	2.80(0.349	256.88(30.5	3.71(0.441
No	277.86(52.6	4.01(0.760	198.17(38.1	2.86(0.551	272.08(48.0	3.93(0.694
Status						
Career	275.59(50.2	3.98(0.726	196.99(35.6	2.84(0.515	268.68(45.1	3.88(0.652
Volunteer	244.72(26.1	3.53(0.378	180.12(28.4	2.60(0.411	233.04(25.4	3.37(0.367
Heavy						
Yes	258.65(44.3	3.73(0.641	186.56(34.6	2.69(0.500	251.55(40.9	3.63(0.591
No	280.40(50.3	4.05(0.728	200.38(34.7	2.89(0.502	272.69(45.5	3.94(0.658

Neither experience with an air pack nor self-reported physical activity had a statistically significant effect on air management. However, participants with prior experience with an air pack reported higher air consumption rates, on average for both psi per minute and cubic feet per minute. Similarly, volunteers that self-reported as physically active, reported higher air consumption rates, on average, for psi per minute and cubic feet per minute.

Despite recruitment attempts targeting female firefighters, only three females (5% of the test population) agreed to participate in the study. The low number of female participants (3) relative to males (56) limits the ability to statistically compare air consumption between males and females. However, one female performed exceptionally well on the air management obstacle course. She finished with the fourth best (lowest) air consumption rate of the test population, has over ten (10) years of experience in the fire service, and is extremely physically active. In regard to the secondary variables that were analyzed, she is also over thirty (30) years old, is a non-smoker, is a career firefighter, and was carrying a gear weight in excess of 65% of her normal body weight. (Normal body weight = 126.8 lbs; Gear weight = 209.4 lbs; Difference = 82.6 lbs)

Other potential factors assessed for an effect on air consumption rates included age (30 years or younger versus over 30 years of age), current smoking status (smoker versus non-smoker), status (career versus volunteer), and heavy gear (turnout gear adding more than 33% of the volunteer's normal body weight). There was a significant difference in median psi per minute and cubic feet per minute between career and volunteer participants ($z = 2.05$; $p = .04$). The median psi per minute for career was 256.99 (min = 202.40; max = 410.59) while the median for volunteer was 232.21 (min =

196.72; max = 268.57). The median cubic feet per minute for career was 3.71 (min = 2.92; max = 5.93) while the median for volunteer was 3.35 (min = 2.84; max = 3.88). These results can be interpreted as volunteers who participated in this study had better (lower) air consumption rates than career firefighters who participated in this study.

There was a marginal difference in median psi per minute and cubic feet per minute between those who were considered to have heavy gear (>33% of normal body weight) and those who did not have heavy gear (<33% of normal body weight), ($z = 1.76$; $p = .07$) The median psi per minute for those who were not wearing heavy gear was 262.81 (min = 202.40; max = 410.59) while the median for those who were wearing heavy gear was 234.63 (min = 196.72; max = 333.35). The median cubic feet per minute for those who were not wearing heavy gear was 3.79 (min = 2.92; max = 5.93), and the median for those who were wearing heavy gear was 3.39 (min = 2.84; max = 4.81). These results can be interpreted as participants who were wearing gear that exceeded 33% of their normal body weight had air consumption rates that were better (lower) than those participants whose gear weight was less than 33% of their normal body weight.

While the correlation between years of service and psi per minute and cubic feet per minute was not statistically significant ($p = .2$), the Spearman Rho correlation coefficient had a value of 0.2, indicating that as years of experience increases, air consumption increases as well. It must be taken into consideration that as years of experience increases, so does the toll that those years of firefighting takes on the human body. All other potential factors did not reflect a statistically significant effect on air consumption.

It is likely that the lack of statistically significant air consumption is due to the large variances reported with all six air consumption measures. A post-hoc power analysis could provide details about the power of this study; however, power analyses conducted after data collection are not valid. (Heisey, 2001) Statistical power to detect a difference if it exists will increase with sample size; future studies with more participants, particularly targeting female firefighters, are necessary to explore factors that affect air consumption more accurately.

Future consideration should be given to utilizing the Scott Electronic Management System (SEMS II) for data collection. The software is receiving air pressure data directly from the self-contained breathing apparatus via Bluetooth technology. When measuring the air levels in the cylinders using the cascade air filling station, a data collector is required to visually measure the air pressure in the cylinder utilizing an analog pressure gauge mounted on the system. When weighing the cylinders, a scale is used, but the scales used in this instance only displayed weight to the nearest tenth of a pound. Because the weight of air is very nominal, the scales need to display the weight to the nearest thousandth of a pound or more to provide more accuracy. For these reasons, the SEMS II software and reporting system is most likely the most accurate of the three measures because it completely eliminates the human error factor in recording results. For that reason, the SEMS II data is the only data discussed in detail.

Assumptions

There were three assumptions considered for this study. The first assumption is that all volunteers for this study were truthful in the data they self-reported on the questionnaire they were asked to complete before participating in the data collection portion of this study. The second assumption is that the Scott Electronic Management System (SEMS II) readings were accurate. The third assumption is that all of the participants in this study were familiar with using self-contained breathing apparatus before the study.

Limitations

Due to the scope of this study, there were several limitations. The first limitation is the limited female population. There were 3 female participants (5%) that participated in this study. However, the national percentage of females in the fire service in 2012 (the last year for which statistics are available) was 3.4%. (http://www.nfpa.org/news-and-research/fire-statistics-and-reports/fire-statistics/the-fire-service/administration/firefighting-occupations-by-women-and-race) This factor should be addressed for further research by specifically recruiting females to participate. The second limitation is the limited accuracy of the cascade air filling station by requiring a visual measurement of air levels on analog pressure gauges. The third limitation is the limited accuracy of weighing the cylinder to calculate the air pressures due to not measuring to thousandths of a pound or smaller increments for greater accuracy. The fourth limitation is the limited ability to determine physical fitness levels for each participant due to the requirement that they self-report on their activity levels. The final limitation is the fact that the air cylinders were not allowed to return to room temperature before taking measurements on the cascade air filling station. While care was taken to fill them slowly so as not to heat the air (and cause it to expand) as the cylinders were filled, they were not allowed to return to room temperature to ensure that the measurements were not affected by a reduced temperature due to being cooled as the participant used the air contained within.

CHAPTER V

DISCUSSION AND CONCLUSIONS

The statistical results of this study indicate that there is no significant difference between experience and self-reported physically active status and the differences between genders could not be determined. Despite these results, air management within the fire service community is still an extremely important topic. If it were not, then there would be zero firefighters killed in the line of duty where “air management” was cited as a contributing factor to their death. The main result that has been realized following this study is that this topic is one that warrants further extensive research to produce significant results that can have a lasting affect across the fire service as a whole.

The fact that no significant differences were detected during the statistical data analysis suggests that the sample size was too small for this type of study. In order to adequately explore the relationships among the variables, a larger population size will be needed. The population size was 59 participants. There were large differences between the number of males versus females and career firefighter versus volunteer firefighters in this study. In order to gain as much insight as possible into the effects of these variables, a power analysis would provide greater insight into how many participant volunteers would be needed to produce a study that showed more significant difference between the variables. In addition, this was a standalone study with no baseline measurements to which the baseline measurements could be compared. It would provide more insight if to have multiple sets of data with a baseline measurement in place. As suggested in the data analysis section, a power analysis should be conducted prior to further research in an effort to determine what size of test population will likely yield significant results. Recruitment was conducted on social media and by word of mouth. For further research, it would be beneficial to bring the Kentucky Fire Commission on board in an effort to utilize their influence and contacts in order to recruit a broader spectrum of participants from across the Commonwealth of Kentucky as well as from all types of fire departments.

The results were surprising due to the research that has previously been conducted. Figure 2 shows a table of the Means of the variables that will be used to discuss these results. Logical reasoning dictates that as firefighters gain more experience in the field of firefighting, they would begin to have better (lower) air consumption rates. These results showed that inexperienced firefighters actually had a better (lower) average air consumption rate. (Experienced = 268.593 psi per minute/3.878 ft^3 per minute; Inexperienced = 260.158 psi per minute/3.757 ft^3 per minute). While this is not statistically significant, this result suggests that physical fitness and age may affect air consumption enough to offset the experience levels of older firefighters because as years of service and experience increases, so does the age of the firefighter.

Logical reasoning based on research suggests that firefighters who are more physically fit are going to have better (lower) air consumption rates (Davis, 2016). However, the results actually show that of the members of the test population who are less physically active have better (lower) average air consumption rates. (Physically Active = 268.390 psi per minute/3.876 ft^3 per minute; Not Physically Active = 262.268 psi per minute/3.787 ft^3 per minute). This result suggests that firefighter with more experience may be able to offset the physical fitness levels of other firefighters by utilizing air management techniques to extend the time they are able to work in their self-contained breathing apparatus (SCBA). Many of the Not Physically Active firefighters who participated in this study are more experienced firefighters who are more accustomed to working in the equipment than the younger, more physically fit firefighters.

The male versus female firefighter population had the greatest numerical discrepancy, and the results are suspect due to the difference in test populations. However, females outperformed males on the air management obstacle course. (Males = 266.547 psi per minute/3.849 ft^3 per minute; Females = 225.253 psi per minute/3.253 ft^3 per minute). This result could be because the females in the test population are generally smaller than many of the males and have less muscle mass. However, two of the females are very physically active. One of the females is experienced while the other two are inexperienced. More of the males were less physically active, but many of the males were more experienced. In light of these results, it is highly evident that more females need to be recruited for further research to determine if this trend will continue with a larger test population.

The younger firefighters outperformed the older firefighters by having a better (lower) average air consumption rate. (Age > 30 = 265.049 psi per minute/3.827 ft^3 per minute; Age < 30 = 263.781 psi per minute/3.809 ft^3 per minute) This result, while not statistically significant, may mean that age does play a role in increasing air consumption rates. Although the difference is small (1.268 psi per minute/0.018 ft^3 per minute), further testing with a larger test population could produce a clearer picture of the effect age has on firefighter air consumption rates.

The firefighters who smoke outperformed the firefighters who do not smoke. (Smoker = 256.877 psi per minute/3.709 ft^3 per minute; Non-Smoker = 272.081 psi per minute/3.929 ft^3 per minute) This result is surprising because the smokers are typically older firefighters who are less physically fit due to a lack of regular physical activity.

Volunteer firefighters outperformed the career firefighters by having a better (lower) average air consumption rate. This test variable did provide a significant difference as discussed in the test results in Chapter 4. (Career = 268.676 psi per minute/3.879 ft^3 per minute; Volunteer = 233.037 psi per minute/3.365 ft^3 per minute) This result is surprising due to the fact that logic would dictate that firefighters who spend more time using and wearing their personal protective equipment and self-contained breathing apparatus would be more accustomed to them and therefore have better average air consumption rates. The results could be due to the effect that age has on the human body. All of the volunteer firefighters who participated were less than thirty (30) years old. However, this set of variables would bear further examination because the test population of volunteer firefighters was only seven (7) participants while the rest of the participants were career firefighters. For further studies, it would be pertinent to recruit a comparable number of volunteers to the numbers of career firefighters who would be participating in those additional studies.

All firefighting gear is heavy, but some firefighters carry a greater percentage of weight in relation to their body size. Firefighters who carried a greater proportion of weight in relation to their body weight (>33%) outperformed firefighters who carried less weight. This test variable provided a slight statistical difference when reviewed as discussed in Chapter 4. (Heavy Gear = 251.546 psi per minute/3.632 ft^3 per minute; Not

Heavy Gear = 272.689 psi per minute/3.938 ft^3 per minute) This test is surprising in light of the fact that bigger, heavier firefighters are more accustomed to carrying the additional weight. However, this difference may be explained by the fact that many of the smaller firefighters are physically active and have less body mass, to begin with. Therefore, muscle is working to move the additional weight as opposed to bigger, less physically active firefighters who are moving additional weight in addition to fatty tissue in their bodies that don't add any additional assistance in moving the mass but instead are part of the mass. (Davis, 2016)

Practical Applications

There are many practical applications for this research. As previously noted, firefighters continue to die in the line of duty, and air management continues to be one of the contributing factors cited in NIOSH reports as a cause of death. Even though the initial test variables did not produce significant differences in the results, it is still extremely important to the fire service that research be conducted to bring awareness to the importance of managing the air supply firefighters take into a hazardous atmosphere with them.

This thesis should be considered a pilot study with further research to be conducted in conjunction with more precise methods of measuring some of the test parameters. For instance, when conducting additional studies regarding the physical fitness of firefighters and the effect it has on air consumption, exercise physiology experts should be brought in to determine physical fitness levels of the test participants. This will provide a clearer picture of how their bodies are utilizing the air and the ability of the body to perform work while wearing the personal protective equipment and self-contained breathing apparatus. Also, seasonality plays a role in air management. The data collection portion of this project was conducted in February which means the participants had been more sedentary through the winter months than they would have been if it had instead been conducted in September following the summer when the participants would have been more active. This initial study should be used as a baseline and compared to air consumption test results conducted at a later date when results can be compared and contrasted to each other.

The statistical results indicate that there is no significant difference between experience and self-reported physically active status and the differences between genders could not be determined. There was a significant difference in median psi per minute and cubic feet per minute between career and volunteer participants ($z = 2.05$; $p = .04$). The median psi per minute for career was 256.99 (min = 202.40; max = 410.59) while the median for volunteer was 232.21 (min = 196.72; max = 268.57). The median cubic feet per minute for career was 3.71 (min = 2.92; max = 5.93) while the median for volunteer was 3.35 (min = 2.84; max = 3.88). There was a marginal difference in median psi per minute and cubic feet per minute between those who were considered to have heavy gear (>33% of normal body weight) and those who did not have heavy gear (<33% of normal body weight), ($z = 1.76$; $p = .07$) The median psi per minute for those who were not wearing heavy gear was 262.81 (min = 202.40; max = 410.59) while the median for those who were wearing heavy gear was 234.63 (min = 196.72; max = 333.35). The median cubic feet per minute for those who were not wearing heavy gear was 3.79 (min = 2.92; max = 5.93) and the median for those who were wearing heavy gear was 3.39 (min =

2.84; max = 4.81). However, the most valuable insight to come from this research is that there is a vast amount of knowledge that must be learned to determine what to focus on to provide methods for firefighters to maximize their efforts to improve their air management.

Further research should be focused on a larger test population with an emphasis on recruiting female firefighters along with volunteer firefighters. In addition to conducting research with firefighters, efforts should be made to bring exercise science professionals on board to provide expertise in the human body and how it responds to work. Grant funding for equipment and personnel can also enhance the ability of further experiments. Valuable insight can be gained by working with other entities that have a better understanding of how the human body and its systems function. While this thesis did not provide the conclusions that were sought from the outset, it provided valuable insights into what must still be done to provide influence across the fire service regarding air management.

APPENDIX

	Excellent	Good	Average	Fair	Poor
Age	28	28.3	31.4	37.9	46.1
Height	68.9	69.3	69.3	70	69.8
Total Weight (lbs)	171.5	177.9	181	191.6	206.1
Lean Weight	145.5	145.1	143.1	141.5	146.2
% Fat	14.8	18.1	20.3	25	28.5
Fat Weight	26	32.58	37.7	50	59.7
Grip Strength	116.6	107.8	105.1	101.3	95.1
Chins	9	7.3	5.2	4.2	0.9
Push-ups	28.3	23.3	17.7	15	10.2
Sit-ups	47.9	45.9	35.1	29.5	22.8
Max VO_2	45.2	43.1	39.2	35.2	34.9
CTT	5:40	5:44	6:50	7:53	10:45

Figure 1 – Fitness Classifications and Work Performance

Source: Davis, P.O. (2016, June) Respiratory Physiology, Ergonomics, and Your SCBA. *Fire Engineering*, p. reprinted

Variable	Mean (PSI per Minute)	Mean (Ft^3 per Minute)
Experienced	268.593	3.8778
Inexperienced	260.158	3.757
Physically Active	268.390	3.876
Not Physically Active	262.268	3.787
Male	266.547	3.849
Female	225.253	3.253
Age > 30	265.049	3.827
Age < 30	263.781	3.809
Smoker	256.877	3.709
Non-Smoker	272.081	3.929
Career	268.676	3.879
Volunteer	233.037	3.365
Heavy Gear	251.546	3.632
Not Heavy Gear	272.689	3.938

Figure 2 – Means for all Study Variables

Air Consumption and Air Management in the Fire Service

Air Management Pre-Test Questionnaire

Identification Number/Unit Number:_____________________________________

1. What is your gender? _____ Male _____ Female

2. How many years have you been in the fire service?

3. What type of workout do you normally participate in and for how long? (Crossfit, P90X, self-guided workout, personal trainer) Please be as specific as you can. (Example: Heavy Weightlifting three times per week for 1 hour each day and Jogging for 3 miles 2 times per week) This information will be used to determine the MET (Metabolic Equivalency of Task) for each workout. This is how the determination will be made between physically fit and non-physically fit participants.

4. Are you a career, volunteer, or part-time firefighter?

5. Do you wish to receive a copy of your air management course results when research is complete? If so, let Wes Broderick know and a copy will be made for your records.

Thank you for volunteering to participate in this research. Hopefully, you will not only gain an understanding of how much work you can perform while breathing from SCBA but will take something back to your own departments to use for improving the fire service as a whole.

Figure 3 – Pre-Obstacle Course Questionnaire

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