An Evaluation of Self Contained Breathing Apparatus Voice Communication Systems

Strategies for Community Risk Reduction

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CERTIFICATION STATEMENT

I hereby certify that this paper constitutes my own product, that where the language of others is set forth, quotation marks so indicate, and that appropriate credit is given where I have used the language, ideas, expressions, or writings of others.

Signed ___________________________
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Abstract

The Monterey Fire Department has experienced difficulty communicating clearly on emergency incidents with personnel wearing SCBA, particularly in the high noise environments associated with interior firefighting and other emergency activities. The problem is that the department has not formally evaluated or implemented any of the technological advances in SCBA communication systems and accessories specifically designed to improve voice communications for SCBA users. The purpose of this research project is to quantitatively evaluate the effectiveness of available SCBA voice communication systems in improving voice communications while wearing an SCBA under simulated emergency incident work conditions.

A comprehensive literature review, evaluative research methodology, and questionnaire were used to answer the following research questions: (a) what types of technologies and voice communication systems are available for the various SCBA utilized in the fire service, (b) what standards, if any, apply to SCBA voice communication systems, (c) which of the available SCBA voice communication systems provide improved voice communications under simulated emergency incident conditions, and (d) which voice communication system, if any, is most effective for the Monterey Fire Department?

Results identify three general categories of SCBA communication systems that are governed by NFPA and ANSI standards. Test results also indicate the integrated speech diaphragm, voice amplification, and wireless radio interface systems were more effective than the hard-wired radio interface system in improving voice communication clarity under simulated emergency incident conditions. Questionnaire results further indicate that the wireless radio

interface and voice amplification systems received higher satisfaction ratings from the subject evaluators than the speech diaphragm or hard-wired radio interface systems, suggesting that Monterey Fire Department personnel would prefer either of the former SCBA communication systems over the latter.

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Introduction

The City of Monterey has experienced a significant number of large fire losses, many of which have presented significant communications challenges, with some resulting in injuries to fire fighters. Communications challenges on the fireground and other emergency scenes became exacerbated beginning in 1951 with the introduction of self-contained breathing apparatus (SCBA), despite the introduction and use of portable radios beginning in the 1970s.

Specifically, the Monterey Fire Department has experienced difficulty communicating clearly on emergency incidents with personnel wearing SCBA, particularly in the high noise environments associated with interior firefighting and other emergency activities. The problem is that the department has not formally evaluated or implemented any of the technological advances in SCBA communication systems and accessories specifically designed to improve voice communications for SCBA users. The purpose of this research project is to quantitatively evaluate the effectiveness of available SCBA voice communication systems in improving voice communications while wearing an SCBA under simulated emergency incident conditions to (1) provide data to assist with a cost/benefit analysis of retrofitting the department’s current SCBA with a voice communications system, and (2) to provide data to assist in the selection of a future SCBA.

A comprehensive literature review, an evaluative research methodology, and a questionnaire were used to answer the following research questions: (a) what types of technologies and voice communication systems are available for the various SCBA utilized in the fire service, (b) what standards, if any, apply to SCBA voice communication systems, (c) which of the available SCBA voice communication systems provides improved voice communications under simulated emergency incident conditions, and (d) which voice communication system, if any, is most effective for the Monterey Fire Department?

Background and Significance

The Monterey Fire Department is a 54-employee career department providing urban and wildland fire suppression, Basic Life Support (BLS) Emergency Medical Services (EMS), hazardous material (Hazmat) release, marine response, urban search and rescue, fire prevention, fire code enforcement, fire origin and cause investigation, disaster preparedness, and community education services to a 10.2 square mile central California coastal community of 30,161 residents (Regional Analysis and Planning Services, p. 4) from three fire stations. Two military educational facilities, a regional community college, and tourism increase the average daily population to approximately 65,000 (Monterey Peninsula College, General Information; Naval Postgraduate School, About NPS; D. Rhoads, personal communication, March 16, 2007; U.S. Army, Installation Fact Sheet). The department responds to approximately 4,500 incidents annually (Response Statistics, 2007), and has automatic mutual aid agreements with the adjoining cities of Seaside and Pacific Grove, as well as the Monterey Peninsula Airport and Pebble Beach Community Services Districts. The City provides contractual fire protection services to nearby Sand City, the Presidio of Monterey Defense Foreign Language Institute, and the Naval Postgraduate School housing areas within Monterey City.

The fire department was formally established in 1890 as a volunteer department with an appointed Fire Chief and one fire station located near the center of the city. Paid staff was hired beginning in about 1930, and the department completed its transition to a fully paid career staff by the early 1950s (City of Monterey, 2007). Two additional fire stations were added in 1951, one in the western section of the city (New Monterey) and the other in the northern section. The department began utilizing respiratory protective equipment in about the 1940s with the Mine Safety Appliances (MSA) Chemox Oxygen Breathing Apparatus, a canister rebreathing apparatus (M. Ventimiglia, personal communication, February 8, 2008). These were later supplemented by one MSA SCBA per fire apparatus beginning in 1951. Both of these early breathing apparatus were replaced with Survivair SCBA in 1972, which were replaced with Interspiro SCBA in 1992. The department purchased its current Interspiro Spiromatic 'S' SCBA in 2001 (K. Zimmerman, personal communication, November 11, 2007), which will be evaluated for replacement beginning in fiscal year 2009-10.

The department's use of portable radios dates back to 1974 with one two-channel radio assigned to each first-out apparatus, intended solely for use by the company officer (M. Cooley, personal communication, March 13, 2008). These were replaced with 16-channel radios in about 1980, with two assigned to each apparatus - one for the officer and the other for the firefighter. Additional radios were purchased in the early 1990s to provide four radios per apparatus and ensure a portable radio for every on-duty firefighter. The City of Monterey and the Salinas Rural Fire Protection District recently received grant funding to provide new digital mobile and portable radios for 24 Monterey County fire agencies, thus standardizing the radio communications equipment used by all county fire agencies. With the imminent deployment of these new radios, the Monterey Fire Department will issue a portable radio to each employee as part of their personal protective equipment.

Monterey has experienced a great number of fires during its 118-year history, many of which included significant communications challenges. In 1924, a large fire involving several large oil storage tanks resulted in the death of three U.S. Army soldiers stationed at the nearby Presidio of Monterey who had volunteered to assist with the fire suppression effort. While no information exists attributing these deaths to poor fireground communications, it is reasonable to infer that these deaths may have been averted with modern communications, fire management models, and fire fighter accountability systems. Another large fire in 1924 destroyed the Del Monte Hotel, which was subsequently rebuilt and is now the main administrative building at the Naval Postgraduate School.

Fires in sardine processing facilities along the city’s historic Cannery Row began to plague the city following the demise of the sardine fishing industry beginning in 1946. The first of these fires in 1948 destroyed the California Packing Company and adjoining Carmel Canning Company. Six other major sardine processing businesses were either significantly damaged or destroyed by fire over the ensuing 18 years, and fires in sardine fishery-related buildings along or near Cannery Row continued through 1986.

Monterey’s fire history also includes many other large commercial and multi-family occupancy fires requiring assistance from neighboring fire agencies. Examples include a large church fire in 1951; an automobile dealership fire in 1953; restaurant fires on Fisherman's Wharf in 1975, 1976, and 1980; a fire involving Fisherman's Wharf in 1982; a furniture store and three adjoining warehouse fire in 1983; and a publishing company warehouse fire in 1986.

Most recently, a five-alarm fire requiring the combined efforts of over 90 firefighters from 20 different agencies destroyed a century-old, two-story building in the city's core downtown business area. Communication challenges were cited in the after-action report, including overloading of the assigned tactical channel and a building evacuation order that took over five minutes to effect due to poor communications with interior firefighters.

This project is significant in that it will provide data useful in determining which type of SCBA voice communication system is most suitable to the Monterey Fire Department. Furthermore, the data will be useful in conducting a cost/benefit analysis of implementing a voice communication system upgrade to the department's current SCBA prior to projected replacement in approximately 2010 – 2011. Lastly, this project will provide data useful in evaluating and selecting the next-generation department SCBA.

This project relates to the following goals and objectives of the Strategies for Community Risk Reduction course: (a) analyze the potential impact of unaddressed community risks, (b) identify benefits associated with successful community risk mitigation, and (c) identify the components of effective risk reduction. The problem this research seeks to answer is related to and supports the following United States Fire Administration (USFA) operational objectives: (a) to reduce firefighter fatalities from fire and (b) to respond appropriately in a timely manner to emerging issues.

Literature Review

The use of respiratory protective equipment can be traced as far back as 50 C.E. when Pliney, a Roman writer, made reference to the use of loose-fitting animal bladders to protect Roman miners from the red oxides of lead (IFSTA, 2002). Italian artist and inventor Leonardo da Vinci also recognized the need for respiratory protection in 1500. Another Italian, Bernardino Ramazzini, the founder of the discipline now known as occupational medicine, also recognized the need for respiratory protection for miners, stone cutters, and mill workers in 1700 (p. 6). The first self-contained breathing apparatus was developed by Alexander Humboldt in Germany in 1795. This was followed by the first air-purifying respirator in 1814. Galibert developed the first oxygen re-breathing device in England in 1864 that was the forerunner of the Type N, Universal gas mask canister used by many fire departments into the 1970s (p. 7). The Gibbs closed-circuit oxygen apparatus, the first SCBA approved by the United States Bureau of Mines for the deep-mining industry, was produced by Mine Safety Appliances (MSA) in 1920 and was also used in the fire service during that period. This was followed by the oxygen-generating breathing apparatus, initially developed for the mining industry in the 1930s. This device utilized the moisture from the wearer’s exhaled breath to create a chemical reaction within the apparatus to produce oxygen and absorb carbon dioxide. This technology was further developed through a contract with the United States Navy during World War II, and these units were widely used in the fire service into the 1970s. Further refinements to the MSA Gibbs closed-circuit SCBA resulted in increased application in the fire service beginning in the 1950s. These units were quite expensive and generally not viewed as necessary by fire department administrators. Prior to the 1970s, fire departments generally provided only one or two SCBA per fire apparatus (p.10).

This changed dramatically in 1970 with the adoption of the United States Occupational Health and Safety Act that established workplace safety regulations, including respiratory protection for fire and emergency services personnel operating in any environment determined to be immediately dangerous to life and health (IDLH) such as interior firefighting. A 1998 amendment, commonly referred to as the “Two-In / Two-Out” rule, requires a minimum of two firefighters wearing positive pressure SCBA and maintaining visual, voice, or signal line communication with each other at all times to enter any IDLH atmosphere, and at least two additional firefighters located outside the IDLH atmosphere wearing positive pressure SCBA prepared to rescue the two interior firefighters if necessary (29 CFR 1910.134, 2007). While this regulation precludes radio communications as the sole tool for accounting for one’s partner during IDLH operations, it does recognize the value of radio communications on the fire ground, including communications between interior firefighting teams and exterior fire fighters.

All respirators, including SCBA, are required to meet National Institute for Occupational Safety and Health (NIOSH) certification standards (42 CFR, Part 84, 2004). These standards establish the types of SCBA to be approved, minimum service duration, and general construction and performance requirements, including protection from specified chemical, biological, and radiological (CBRN) hazards. In addition, the standards contained in National Fire Protection Association (NFPA) 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus for Emergency Services* (NFPA, 2007) also apply to any SCBA used for firefighting or other emergency service application. This standard, originally adopted in 1971 as Standard 19B, *Standard on Respiratory Protective Equipment for Fire Fighters,* was replaced in 1981 with Standard 1981 that establishes certification, labeling, design, performance, and testing requirements for positive-pressure SCBA. Performance standards for voice communications were first included in the 1987 edition of this standard and subsequently amended in the 1992 and 2007 editions (NFPA, 1987, 1992, 2007). Under this NFPA standard, test procedures for SCBA voice communications systems are derived from American National Standards Institute (ANSI) Standard 3.2 (1999), *American National Standard Method for Measuring the Intelligibility of Speech over Communications Systems.* The latest 2007 edition makes the communication performance test more stringent than previous editions by raising the pass/fail criteria from 72% to 85%. This test establishes the procedures to measure the intelligibility of speech over voice communication systems in a controlled environment. Reed (2007) reported that, although NFPA 1981 does not require voice amplification or other types of communication interfaces to meet the communications performance standard, most SCBA manufacturers will likely utilize voice amplification to meet the more stringent standard.

SCBA voice communication systems were first introduced in 1962 when Survivair introduced a voice amplifier (S. Weinstein, personal communication, April 8, 2008). The St. Louis Fire Department was one of the first fire departments to evaluate a radio interface in 1965 (Wertich, 1965). Today, all SCBA manufacturers have voice amplification and/or radio interface systems available. Most have a speech diaphragm or microphone integrated into the facepiece to enhance speech communication. Interviews of firefighters who regularly use SCBA radio interface systems indicate they find that they provide clearer voice communication (Cook, 2002).

The United States Fire Administration reports that “recent incidents involving firefighter fatalities clearly demonstrate that, despite technological advances in communications equipment, important information is not always adequately communicated on the fireground or emergency scene” (USFA, 1999). Inadequate communication often adversely impacts the safety of firefighters, rescue workers, and civilians, and is repeatedly cited as a contributing factor in many incidents reported through the United States Fire Administration Major Fires Investigation Project. The USFA identified several factors adversely affecting emergency incident communications, including (1) unsuitable equipment, (2) equipment failure, (3) inadequate system capacity, (4) interference, (5) radio discipline, (6) situation reporting, (7) incident management, (8) cultural values, (9) chain of command, and (10) problem reporting. The predominant communication-related concern reported by firefighters and company officers is the difficulty in communicating while using self-contained breathing apparatus, both face-to-face and via portable radio (p. 4). While few firefighters are unfamiliar with this problem, safety regulations and incident management practices dictate that firefighters *both* use SCBA *and* communicate effectively. SCBA manufacturers are cognizant of this issue and have developed a variety of solutions to date, including speech ports or diaphragms, facepiece integrated voice amplifiers, intercom systems, portable radio interfaces, and throat and “bone” microphones. Most of these systems have received mixed reviews from firefighters in the field, and the costs of these systems are prohibitive for many departments (p. 5).

In a recent research project asking firefighters to identify the most important features to consider when considering an ideal SCBA, 77% of the respondents identified improved voice communication as the most important attribute (Piland, 2003). SCBA manufacturers have responded to user demands by continuing to provide advances in voice communication systems. Manufacturers currently providing NIOSH and NFPA-compliant positive pressure, open-circuit SCBA for fire fighting and emergency services in the United States include Avon-ISI, Draeger Safety, Interspiro, MSA, Scott Health and Safety, and Sperian Survivair. Each of these manufacturers provides one or more voice communication system options.

Avon-ISI recently introduced the Viking model Z Seven SCBA, which includes a user-adjustable electronic voice amplification system utilizing a microphone inside the nose cup. This device is automatically activated whenever the user opens the air cylinder valve or activates any other electronic SCBA device, such as the personal alert safety system (PASS) or heads-up display (HUD) (Firehouse, 2007). The Viking Z Seven also has a proprietary wireless radio interface option that the manufacturer reports extends battery life and reduces signal interference more effectively than Bluetooth® technology (Avon-ISI, 2007). Avon-ISI declined a request for more information regarding the wireless radio technology utilized in the Viking Z Seven, stating it was proprietary information. Avon-ISI also offers an electronic voice amplifier and wired portable radio interface for their earlier model Viking SCBA (Avon-ISI).

Draeger Safety has also developed a new SCBA, the PSS 7000, which includes a fully-integrated communications system with two speakers, electronic voice amplification system, and hard-wired portable radio interface (Firehouse, 2007). Efforts to determine whether Draeger Safety provides voice communication systems or accessories for earlier model SCBA were not successful.

Interspiro introduced their latest generation SCBA that meets the 2007 edition of NFPA 1981, the Spiromatic S6, in August 2007 (Interspiro, 2007). Interspiro does not offer any new voice communications accessories for this model; however, their earlier Spiromatic S4 and S5 electronic Voice Projection Unit (VPU) and Savox 400 and 500 hard-wired portable radio interfaces remain compatible with this model (Interspiro, 2007).

MSA offers both a mechanical speech diaphragm and an electronic voice amplification radio interface option for their FireHawk M7 SCBA (MSA, 2007). The electronic amplifier features an internal facepiece microphone, digital signal processor to eliminate feedback, three user-selected volume levels, and an auto-off feature to increase battery life (MSA, 2007). This same voice amplification communication system is also compatible with their earlier Ultra Elite SCBA facepiece (K. McMillan, personal communication, April 10, 2008).

Scott Health and Safety offers the EPIC electronic voice amplifier and EPIC wireless communications system with their newest-generation SCBA, the Air-Pak 75. The electronic voice amplifier features a directional speaker and auto shut-off, and the wireless communications system includes both the electronic voice amplifier and a portable radio interface utilizing Bluetooth® wireless technology (Scott, 2007). Both systems are available on either the AV-2000 or AV-3000 facepiece, which are also compatible with earlier Air-Pak models (T. Topf, personal communication, April 16, 2008).

Bluetooth® is a wireless communication specification standard utilizing the unlicensed industrial, scientific and medical (ISM) band at 2.4 to 2.485 GHz, which also utilizes a spread spectrum adaptive frequency hopping (AFH) technology to eliminate interference (Bluetooth SIG, 2008). Bluetooth® signals hop among 79 frequencies at 1 MHz intervals, avoiding those frequencies being utilized by other wireless devices sharing the same radio spectrum. Bluetooth® devices operate at 2.5 mW power and typically have a range of up to 33 feet.

Sperian Survivair offers their CommCommand electronic voice amplification system and CommCommand wireless radio communication interface on their latest-generation Warrior

SCBA (Sperian, 2007). The CommCommand voice amplification system features a large speaker and push-to-talk (PTT) or hands-free operation. The CommCommand wireless radio interface features digital spread spectrum (DSS) technology and an integrated facepiece speaker. DSS technology utilizes multiple radio signals, which are transmitted over a wide range of the 2.4 GHz spectrum and then collected into their original frequency at the receiver (Americom, n.d.). Spread spectrum signals utilize wide band, noise-like signals that are resistant to interception and interference from narrow band signals. The CommCommand wireless radio interface also features an independent lapel microphone, compatible with most available portable radios, with a PTT switch and speaker. Both systems are available on their newest TwentyTwenty Plus facepiece. Survivair also offers their Classic SmallTalk and SmallTalk Plus mask-mounted electronic voice amplifiers and their RCS radio interface system with internal microphone and adjustable ear speaker for their earlier-generation Panther, Sigma, and Cougar SCBAs (S. Weinstein, personal communication, April 8, 2008).

Emerging technologies include PC-based telemetry systems with the ability to monitor multiple users' identification and personal information, cylinder pressure, remaining time to low-pressure alarm activation, and transmit a building evacuation alarm to the SCBA wearer (Digney, 2007). Newer communication technologies, combined with firefighter education and training, should continue to improve firefighter safety (Coleman, 2003).

In summary, the literature review shows that all respirators must comply with the general construction and performance requirements established by federal safety regulations, and SCBA used for firefighting or other emergency services also comply with the non-regulatory consensus standards established by the National Fire Protection Association. Data from the literature review also indicates that SCBA manufacturers utilize three general categories of voice communication technology: (1) speech diaphragm or port, (2) voice amplification, and (3) radio interface. The data further suggests that poor communications is the predominant concern of firefighters while using SCBA, and inadequate communications in general are often cited as a contributing factor in firefighter fatality and near-miss incidents. Six manufacturers provide NIOSH and NFPA-compliant SCBA in the United States, and each offers one or more of the three categories of voice communication system technology. No literature was found specifically evaluating or comparing any of these voice communication system technologies to date.

Procedures

Data from a literature review was utilized to answer research question (a): What types of technologies and voice communication systems are available for the various SCBA utilized in the fire service? Data from a literature review was also utilized to answer research question (b): What standards, if any, apply to SCBA voice communication systems?

The following procedures were utilized to answer research question (c): Which of the available SCBA voice communication systems provide improved voice communications under simulated emergency incident conditions? These procedures approximate those specified in NFPA 1981 for testing of SCBA voice communications systems (NFPA, 2007) and the American National Standards Institute (ANSI) for measuring the intelligibility of speech over communications systems (ANSI S3.2, 1999) with the following major exceptions: (a) procedures did not utilize a test chamber that absorbs a minimum of 90 percent of all sound from 500 Hz to 5000 Hz; (b) procedures utilized a SCBA facepiece only, rather than the complete SCBA; and

(c) test procedures were conducted with the test subjects on an exercise treadmill to simulate conditions similar to the strenuous work encountered during an emergency incident.

Ten volunteer test subjects from the Monterey Fire Department were utilized - five as subject talkers and five as subject listeners. The test subjects were solicited utilizing an electronic mail message (Appendix A) sent to the 48 SCBA user population within the department. The volunteer subject listeners and talkers represent the minimum sampling of talkers and listeners recommended by NFPA for testing SCBA voice communications systems (NFPA, 2007). The selected sampling also represents the 48-person user population as shown in Table 1.

Table 1

Test Subject Sampling Summary

Test Subject	**Rank**	**Gender**	**Age**	**Years of Service**
Talker 1	Div. Chief	M	54	33
Talker 2	Captain	M	48	20
Talker 3	Captain	M	36	8
Talker 4	Captain	M	39	15
Talker 5	Captain	M	38	8
Average			**43**	**16.8**
Listener A	Engineer	M	44	8
Listener B	Captain	M	53	33
Listener C	Div. Chief	M	53	32
Listener D	Div. Chief	M	51	28
Listener E	Div. Chief	M	44	28
Average			**49**	**25.8**

All subject talkers and listeners were asked and confirmed that English was their native language, and all listeners were determined to have audiometrically normal hearing for their age group by review of their most recent department-provided medical evaluation report (within past twelve months). Subject talkers were also evaluated and determined not to have any obvious speech defect or strong regional accent (NFPA, 2007).

All subject talkers and listeners were provided a 300-word monosyllabic stimulus English word list (ANSI S3.2, 1999) one day prior to the test evaluation procedures (Appendix B). Both talkers and listeners were instructed to become thoroughly familiar with the word list prior to the test procedures. Talkers were trained to recite the following carrier sentence, including pre-selected words from the 300-word monosyllabic stimulus word list: “number [list sequence number]; circle [list word] now” (Appendix C). Talkers were trained and monitored throughout the test procedure to enunciate the words of the carrier sentence clearly, without placing emphasis on any word(s), at a sound level of 75-85 dBA without an SCBA facepiece measured at five feet distance at the height of the listener’s ear. Talker sound level was measured using a Quest Technologies Model 210 sound level meter, calibrated prior to each measurement in accordance with the manufacturer’s instructions. Talkers were trained and monitored to recite the carrier sentence for each test word at a pace of one every 5-6 seconds. Talkers were instructed and monitored to use the same voice level with or without an SCBA facepiece.

Test procedures for the five subject talkers were conducted on March 29 and 30, 2008. The test environment was a 700 square-foot insulated room within an unattached 900 square-foot building designated as the city Emergency Operations Center and Training Facility. This building is situated 150 feet from the nearest street, and is shielded on the two sides exposed to traffic noise by a combination fire station and police administration building. The test environment was maintained at 68 degrees Fahrenheit, ±1 degree, and 40% relative humidity, ±5%, throughout the test procedures as measured utilizing a Nielsen-Kellerman Kestrel model 3000 pocket weather instrument. The test room has carpet flooring, insulated walls, and window openings limited to the top eighteen inches of two walls. The two doors and all windows were closed during the test procedures, and the window shades were also closed throughout the test procedures to minimize exterior noise interference. There were no radios, telephones, or other sources of interior noise interference operating within the test environment during the test procedures. The ambient sound level within the test environment, measured without any test equipment operating, was <5 dBA before and after each test sequence. This test environment was selected as the best available site with the most opportunity to control noise interference variables. The test environment was filled with digital broadband "pink" noise, with a tolerance of 6dB per octave band from 400 Hz to 4000 Hz from a pre-recorded compact disc (Media College). The "pink" noise was amplified through a Sony Model CFD C1000 portable audio system to achieve a sound level of 70 dB, ±2 dB, in combination with the treadmill sound level, at the listener's head position, without listeners present (NFPA, 2007). The sound level was measured using a Quest Technologies Model 210 sound level meter, calibrated prior to each measurement in accordance with the manufacturer's instructions.

The subject talker was instructed to randomly select one of ten 50-word lists created from the 300-word master list (Appendix C) for each test sequence. The ten 50-word lists were each constructed by randomly selecting one word from each of the 50 six-word groupings from the master word list (Appendix B). The ten different 50-word lists were selected and utilized by the subject talkers as summarized in Table 2. Subject talkers were then instructed to read the selected list of 50 monosyllabic English rhyme words, reciting each word singularly within the prescribed carrier sentence, maintaining the volume and pace described earlier.

Table 2

Talker Word List Use Summary

Word List	Times Selected	Percentage
#1	3	12.50%
#2	2	8.33%
#3	4	16.66%
#4	2	8.33%
#5	3	12.50%
#6	1	4.17%
#7	3	12.50%
#8	2	8.33%
#9	3	12.50%
#10	1	4.17%
Total	**24**	**100.00%**

To simulate working conditions encountered during an emergency incident, subject talkers were placed on a Woodway model MERCS exercise treadmill within the test environment for each test sequence. After a three-minute warm-up at 0^o elevation and 1.5 mph speed, the treadmill elevation and speed were adjusted incrementally to achieve and maintain a 70% - 80% maximal heart rate for each subject talker. Each test subject's target heart rate (THR) was established using the Karvonen Method (Baechle & Earle, 2000) and calculated utilizing the worksheet in Appendix D. Each test subject's heart rate was monitored continually throughout the test procedures utilizing a Polar Model FS1 digital heart rate monitor. Test subjects were also continually evaluated for signs of poor perfusion, shortness of breath, and physical or verbal manifestations of fatigue. All test subjects described themselves as in excellent physical condition and regular participants in the department wellness and fitness program.

The subject talkers were then recorded as they recited each word list utilizing Microsoft Sound Recorder (version 5.1) and Realtek High Definition Audio Manager (version 5.10) software installed on a Fujitsu model E-8310 portable computer. A Radio Shack remote microphone was situated 2 feet, ±6 inches in front of the talker's face at mouth level for non-portable radio interface test sequences. For test sequences utilizing a portable radio interface, a receiver radio was placed on a table ten feet in front of the exercise treadmill, facing away from the subject talker, with the microphone located 12 inches in front of the radio speaker at speaker level. The portable radio volume was adjusted to achieve a sound level of 75-85 dBA, measured 12 inches in front of the radio speaker. Talkers were monitored to ensure conformance with the word list specified for each test sequence. Subject listeners were not present during this portion of the test procedures.

Each subject talker selected and recited a separate random 50-word list for each of the following 5 test sequences: test sequence #1 did not utilize a SCBA facepiece or any SCBA voice communication system to establish a test baseline; test sequence #2 utilized a Sperian/Survivair Tweny-Twenty Plus SCBA facepiece with the integrated speech diaphragm and without any additional voice communication system accessories; test sequence #3 utilized a Sperian/Survivair Tweny-Twenty Plus SCBA facepiece with an attached Sperian

CommCommand electronic voice amplification system; test sequence #4 utilized an Interspiro Spiromatic SCBA facepiece with a Savox model 500 hard-wired portable radio interface; test sequence #5 utilized a Sperian/Survivair Twenty-Twenty Plus SCBA facepiece with the Sperian Survivair CommCommand wireless radio communications interface. Only SCBA facepieces were utilized for test sequences 2-5. Complete SCBA systems were not utilized due to excessive sound interference resulting from the inhalation and exhalation noise associated with breathing from of the compressed air supply. For test sequences utilizing a portable radio interface accessory, two Motorola model MT-2000 portable VHF radios were utilized and set to transmit and receive on 155.2350 MHz at 1 watt power. All subject talkers performed and passed a qualitative facepiece-to-face fit test consistent with federal regulations (29 CFR, Part 1910.134, 2007) prior to the initiation of the test procedures. Talkers were permitted to rest between test sequences, if desired, and were returned to the 70% - 80% target heart rate on the exercise treadmill before initiating the next test sequence.

Test procedures for the five subject listeners were conducted on Monday, March 31, 2008 within the same test environment. Subject listeners were provided the 300-word monosyllabic English modified rhyme word list, separated into 50 sets of six similar sounding words (Appendix B). The listeners were instructed and trained to circle each word as they hear it recited by the talker. The five listeners were seated at two adjoining tables in the center of the test environment, separated by 24-inch x 24-inch cardboard dividers to prevent visual cues or bias. The test environment was again filled with broadband digital “pink” noise, with a tolerance of 6dB per octave band from 400 Hz to 4000 Hz, from a pre-recorded digital compact disc, amplified through a Sony Model CFD C1000 portable audio system with the two speakers oriented away from the listener group and adjusted to achieve a sound level of 70 dB, ±2dB at the center listener’s head position. The sound level was measured using a Quest Technologies Model 210 sound level meter, calibrated prior to each measurement in accordance with the manufacturer’s instructions.

The 25 previously recorded talker word lists were then replayed sequentially through a Craig model CD6908 portable audio system. The audio system was situated on a table 10 feet in front of and facing the listener table directly in front of the center listener. The audio volume was adjusted to achieve a sound level of 75 – 85 dBA, measured five feet in front of each speaker. Each listener then completed a separate word selection list for each of the five recorded test sequences for each of the five subject talkers, for a total of 25 word selection lists per listener. The listener group completed the 25 test sequences in a single session divided into three consecutive 60-minute periods with a 10-minute break between periods. Listeners were monitored throughout the test process, including breaks, to ensure conformance with test instructions and procedures.

Each listener response list was then scored to reflect the number of correct responses compared to the 50 words recited. Raw scores were verified by a test assistant. The average raw score was calculated for each talker and listener for each test sequence, and the average raw score was then calculated for the 5-talker group and 5-listener group for each test sequence. The standard deviation of raw scores for each talker was calculated for each test sequence, as was the average standard deviation for the group of talkers for each test sequence. A score value was then calculated by dividing the average raw score for each talker for each voice communication system tested by the corresponding average raw score for the same talker for the baseline test sequence (no SCBA facepiece). The average score value for all talkers was calculated for each voice communication system evaluated as the factor established in NFPA Standard 1981 (2007) to determine whether or not a voice communication system meets the minimum established performance threshold of 85%.

To answer research question (d), “Which voice communication system, if any, is most effective for the Monterey Fire Department,” subject talkers were instructed to complete a questionnaire (Appendix E) at the conclusion of test sequences 2 – 5, evaluating the voice communication technology and system tested. Subject talkers completed a separate evaluation questionnaire, consisting of 13 closed-end rating scale questions for each communication system evaluated.

The evaluation questionnaire was developed utilizing an internet-based survey of the 48-member user population rating the importance of various SCBA communications system factors (Appendix F). The survey consisted of 14 closed-end rating scale questions, followed by one open-ended multiple response question to capture factors not included in the closed-end questions. The closed-end questions were developed to evaluate the relative importance of SCBA voice communication system factors derived from (a) the literature review and (b) from informal discussions and comments provided by department SCBA users relating to SCBA communication systems over the previous 18 months. The survey was distributed through a commercial survey website by electronic mail solicitation to the 48-member fire department user population on March 19, 2008.

This study is not intended to be an exhaustive evaluation of all available SCBA voice communications systems and products, rather it is an evaluation of representative examples of the various available voice communication systems and technologies. Thus, similar systems and technologies from different manufacturers were not evaluated. While it was initially desired to include the various types of voice communication systems and technologies available for the current department-issued Interspiro Spiromatic ‘S’ SCBA, the manufacturer was unable to provide an example of their voice amplification system in sufficient time to meet the test schedule. The Sperian/Survivair Twenty-Twenty Plus SCBA facepiece was selected and utilized to evaluate facepiece voice diaphragm, voice amplification, and wireless portable radio interface systems, and the Interspiro Spiromatic facepiece was utilized to evaluate hard-wired portable radio interface systems. Furthermore, this study focused solely on one-way communications from the SCBA user to a non-SCBA listener and did not evaluate the effectiveness of heard communications for the SCBA user with the various SCBA voice communication systems.

Results

For research question (a), “What types of technologies and voice communication systems are available for SCBA utilized in the fire service,” data derived from the literature review indicates three broad categories of voice communication systems are utilized by the various SCBA manufacturers. The first is a speech diaphragm or speech port integral to the SCBA facepiece design and intended to provide improved voice communication clarity without amplification or electronic enhancement over a non-speech diaphragm or port equipped facepiece. Most manufacturers incorporate this technology into their current SCBA facepieces. The second category is a mechanical or electronic voice amplifier attached to or integrated into the SCBA facepiece. MSA offers a mechanical voice amplifier, and Avon-ISI, Draeger Safety, Interspiro, MSA, Scott Health and Safety, and Sperian Survivair utilize electronic voice amplification systems. These are battery-powered, with the on/off or push-to-talk (PTT) switch located on the voice amplifier.

The third category of voice communication system is a portable radio interface. Hard-wired portable radio interfaces are available from Avon-ISI, Draeger Safety, and Interspiro. These systems include various types and styles of throat, bone, helmet-mounted, and facepiece-mounted or integrated microphones and speakers. Wireless portable radio interfaces are available from Avon-ISI, Scott Health and Safety, and Sperian Survivair. Avon-ISI utilizes a proprietary wireless technology, Scott Health and Safety utilizes Bluetooth® wireless technology, and Sperian Survivair utilizes digital spread spectrum (DSS) wireless technology.

For research question (b), “What standards, if any, apply to SCBA voice communication systems,” data from the literature review indicates that general SCBA construction and performance requirements are governed by federal safety regulations contained in National Institute for Occupational Safety and Health (NIOSH) standards (42 CFR, Part 84, 2004). These regulations establish the types of SCBA to be approved, minimum service duration, and general construction and performance requirements, including protection from specified chemical, biological, and radiological (CBRN) hazards. SCBA used for firefighting or other emergency service applications are also governed indirectly by the consensus standards contained in National Fire Protection Association (NFPA) 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus for Emergency Services* (NFPA, 2007). This standard establishes certification, labeling, design, performance, and testing requirements for positive-pressure SCBA. This standard also establishes minimum performance standards for SCBA voice communications systems utilizing test procedures derived from the American National Standards

Institute (ANSI) Standard 3.2 (1999), *American National Standard Method for Measuring the Intelligibility of Speech over Communications Systems*, which establishes the procedures to measure the intelligibility of speech over voice communication systems in a controlled environment. The latest edition of NFPA 1981 raises the minimum passing score for voice communication systems from 72% to 85%. Although NFPA standards are consensus-based, non-regulatory standards, all SCBA manufacturers comply with these standards as an industry practice.

For research question (c), "Which of the available SCBA voice communication systems provides improved voice communications under simulated emergency incident conditions," test data are shown in Table 2 through Table 6. The data in each table reflects the raw score of each listener response word list as determined by the number of correct responses of the 50 words recited.

Table 2

Test Data – Sequence #1 (No SCBA facepiece) *n=5*

	Talker 1	**Talker 2**	**Talker 3**	**Talker 4**	**Talker 5**	**Totals**	**Average**
Listener A	47	47	49	45	46	**234**	**46.8**
Listener B	44	48	48	47	47	**234**	**46.8**
Listener C	48	48	47	46	45	**234**	**46.8**
Listener D	49	48	46	45	47	**235**	**47.0**
Listener E	46	49	48	44	47	**234**	**46.8**
Total Score	**234**	**240**	**238**	**227**	**232**	**234.2**	
Average Score	**46.8**	**48.0**	**47.6**	**45.4**	**46.4**		**46.84**
SD	**1.92**	**0.71**	**1.14**	**1.14**	**0.89**		**1.16**

Table 3

Test Data – Sequence #2 (Speech diaphragm system) *n=5*

	Talker 1	Talker 2	Talker 3	Talker 4	Talker 5	Totals	Average
Listener A	37	43	35	41	38	**194**	**38.8**
Listener B	40	41	30	40	36	**187**	**37.4**
Listener C	42	37	27	34	35	**175**	**35.0**
Listener D	39	39	26	42	35	**181**	**36.2**
Listener E	42	41	29	32	36	**180**	**36.0**
Total Score	**200**	**201**	**147**	**189**	**180**	**183.4**	
Average Score	**40.0**	**40.2**	**29.4**	**37.8**	**36.0**		**36.68**
SD	**2.12**	**2.28**	**3.51**	**4.49**	**1.22**		**2.72**
Score Value	**85.47**	**83.75**	**61.76**	**83.26**	**77.59**		**78.37**

Table 4

Test Data – Sequence #3 (Voice amplification system) *n=5*

	Talker 1	Talker 2	Talker 3	Talker 4	Talker 5	Totals	Average
Listener A	38	40	27	45	42	**192**	**38.4**
Listener B	36	36	24	38	42	**176**	**35.2**
Listener C	41	35	20	36	40	**172**	**34.4**
Listener D	38	35	24	33	45	**175**	**35.0**
Listener E	43	36	23	39	41	**182**	**36.4**
Total Score	**196**	**182**	**118**	**191**	**210**	**179.4**	
Average Score	**39.2**	**36.4**	**23.6**	**38.2**	**42.0**		**35.88**
SD	**2.77**	**2.07**	**2.51**	**4.44**	**1.87**		**2.73**
Score Value	**83.76**	**75.83**	**49.58**	**84.14**	**90.52**		**76.77**

Table 5

Test Data – Sequence #4 (Hard-wired radio interface system) *n=5*

	Talker 1	Talker 2	Talker 3	Talker 4	Talker 5	Totals	Average
Listener A	34	34	30	24	0[1]	**122**	**30.5**
Listener B	35	24	27	26	0[1]	**112**	**28.0**
Listener C	28	23	18	21	0[1]	**90**	**22.5**
Listener D	31	26	25	27	0[1]	**109**	**27.25**
Listener E	38	24	21	25	0[1]	**108**	**27.0**
Total Score	**166**	**131**	**121**	**123**	**0**	**135.25**	
Average Score	**33.2**	**26.2**	**24.2**	**24.6**	**0**		**33.81**
SD	**3.83**	**4.49**	**4.76**	**2.30**	**0**		**3.84**
Score Value	**70.94**	**54.58**	**50.84**	**54.19**	**0**		**57.64**

[1] Unable to complete test sequence due to obscured facepiece (fogging)

Table 6

Test Data – Sequence #5 (Wireless radio interface system) *n=5*

	Talker 1	Talker 2	Talker 3	Talker 4	Talker 5	Total	Average
Listener A	38	38	36	38	0[2]	**150**	**37.5**
Listener B	31	34	37	35	0[2]	**137**	**34.25**
Listener C	38	35	31	30	0[2]	**134**	**33.5**
Listener D	32	31	31	34	0[2]	**128**	**32.0**
Listener E	36	32	32	32	0[2]	**132**	**33.0**
Total Score	**175**	**170**	**167**	**169**	**0**	**170.25**	
Average Score	**35.0**	**34.0**	**33.4**	**33.8**	**0**		**42.56**
SD	**3.32**	**2.74**	**2.88**	**3.03**	**0**		**2.99**
Score Value	**74.79**	**70.83**	**70.17**	**74.45**	**0**		**72.56**

[2] Unable to complete test sequence due to audio recording equipment malfunction

This data indicates that the speech diaphragm provided the clearest voice communication of all SCBA communication systems evaluated. The data further indicates that the electronic voice amplifier was two percent less effective than the speech diaphragm, which was five percent less effective than the wireless radio interface. The hard-wired radio interface was significantly (20%) less effective than the wireless radio interface.

The data further indicates similar results when comparing the mean score values (s.v.). The speech diaphragm achieved the highest mean score value (78.37%), followed by the electronic voice amplifier (76.77%), wireless radio interface (72.56%), and hard-wired radio interface (57.64%). None of these systems, however, met the minimum passing score value of 85% established for SCBA voice communication systems (NFPA, 2007).

The test data also shows no results for Talker #5 in test sequence #4. This was due to the subject's inability to read the prescribed word list as a result of fogging of the SCBA facepiece. This was not a problem for any of the other four subject talkers, and an additional volunteer test subject was not available within the time constraints of the test procedures. Furthermore, there is no test data for Talker #5 in test sequence #5 due to a malfunction of the audio recording equipment, which was not discovered until after the completion of talker test procedures, with insufficient time to replicate.

Overall, the test data indicates that the speech diaphragm, voice amplifier, and wireless radio interface SCBA provide similar effectiveness relative to voice communication clarity.

For research question (d), "Which SCBA voice communication system, if any, is most effective for the Monterey Fire Department," questionnaire results are shown in Tables 7-10. Responses were categorized as "not a factor" if that rating was selected, "low satisfaction" if box 1-5 on the rating scale was selected, or "high satisfaction" if box 6-10 was selected.

Table 7

Questionnaire Results – Test Sequence #2 (Speech diaphragm system) n=5

Question	SCBA Communication System Factor	Responses Indicating Not a Factor	Responses Indicating Low Satisfaction	Responses Indicating High Satisfaction
1.	**Donning time**	0	0	5
2.	**Ease of system setup**	0	1	4
3.	**Ease of system activation**	0	1	4
4.	**Ease of system operation**	0	1	4
5.	**Location of system activation controls**	5	0	0
6.	**Operation of system controls with gloves**	5	0	0
7.	**Facepiece configuration**	0	2	3
8.	**System weight**	0	0	5
9.	**System bulk**	0	0	5
10.	**Tangle or snag potential**	0	0	5
11.	**Perceived ruggedness/durability**	0	0	5
12.	**Confidence in system**	0	4	1
13.	**Comparison to other technologies evaluated.**	0	4	1
	Response Totals	**10**	**13**	**42**

Table 8

Questionnaire Results – Test Sequence #3 (Voice amplification system) *n=5*

Question	SCBA Communication System Factor	Responses Indicating Not a Factor	Responses Indicating Low Satisfaction	Responses Indicating High Satisfaction
1.	**Donning time**	0	0	5
2.	**Ease of system setup**	0	0	5
3.	**Ease of system activation**	0	1	4
4.	**Ease of system operation**	0	0	5
5.	**Location of system activation controls**	0	1	4
6.	**Operation of system controls with gloves**	0	1	4
7.	**Facepiece configuration**	0	0	5
8.	**System weight**	0	1	4
9.	**System bulk**	0	1	4
10.	**Tangle or snag potential**	0	0	5
11.	**Perceived ruggedness/durability**	0	1	4
12.	**Confidence in system**	0	1	4
13.	**Comparison to other technologies evaluated.**	0	2	3
	Response Totals	**0**	**9**	**56**

Table 9

Questionnaire Results – Test Sequence #4 (hard-wired radio interface system) n=5

Question	SCBA Communication System Factor	Responses Indicating Not a Factor	Responses Indicating Low Satisfaction	Responses Indicating High Satisfaction
1.	**Donning time**	0	3	2
2.	**Ease of system setup**	0	3	2
3.	**Ease of system activation**	0	3	2
4.	**Ease of system operation**	0	1	4
5.	**Location of system activation controls**	0	3	2
6.	**Operation of system controls with gloves**	0	3	2
7.	**Facepiece configuration**	0	3	2
8.	**System weight**	0	1	4
9.	**System bulk**	0	2	3
10.	**Tangle or snag potential**	0	4	1
11.	**Perceived ruggedness/durability**	0	3	2
12.	**Confidence in system**	0	3	2
13.	**Comparison to other technologies evaluated.**	0	4	1
	Response Totals	**0**	**36**	**29**

Table 10

Questionnaire Results – Test Sequence #5 (wireless radio interface system) *n=5*

Question	SCBA Communication System Factor	Responses Indicating Not a Factor	Responses Indicating Low Satisfaction	Responses Indicating High Satisfaction
1.	**Donning time**	0	0	5
2.	**Ease of system setup**	0	0	5
3.	**Ease of system activation**	0	0	5
4.	**Ease of system operation**	0	0	5
5.	**Location of system activation controls**	0	0	5
6.	**Operation of system controls with gloves**	0	1	4
7.	**Facepiece configuration**	0	0	5
8.	**System weight**	0	1	4
9.	**System bulk**	0	0	5
10.	**Tangle or snag potential**	0	0	5
11.	**Perceived ruggedness/durability**	0	0	5
12.	**Confidence in system**	0	0	5
13.	**Compareison to other technologies evaluated.**	0	0	5
	Response Totals	**0**	**2**	**63**

The data from these tables indicate that the wireless radio interface received the highest high-satisfaction score (96.9%) and the lowest low-satisfaction score (3.1%), followed closely by the electronic voice amplifier at 86.2% and 13.8% respectively. The speech diaphragm and hard-wired radio interface systems received significantly lower high-satisfaction scores (64.6% and 44.6%) with correspondingly higher low-satisfaction scores (20.0% and 53.4%), however if the two "not a factor" ratings are ignored for the speech diaphragm, the user satisfaction score increases to 76.4%.

In summary, results indicate that manufacturers utilize one or more solutions from three technology categories to improve voice communications for SCBA users, and these communication systems are governed by NFPA and ANSI standards. Test results also indicate that the integrated speech diaphragm, voice amplifier, and wireless radio interface systems are more effective than the hard-wired radio interface in improving SCBA voice communication clarity under simulated emergency conditions. Furthermore, the data from the user questionnaire indicates that the wireless radio interface system and voice amplification system received higher satisfaction ratings than the speech diaphragm and hard-wired radio interface systems.

Discussion

The results for research question (a), “What types of technologies and voice communication systems are available for SCBAs utilized in the fire service,” are consistent with the literature on this subject. Voice amplification systems have been utilized since 1962 (S. Weinstein, personal communication, April 8, 2008), and Wertich (1965) reported on an early evaluation of radio interfaces. More recently, Cook (2002) reported that firefighters who regularly use SCBA radio interface systems found that they provide clearer communication. Recent literature (Firehouse, 2007) also indicates that all SCBA manufacturers provide a voice amplification system and either a hard-wired or wireless radio interface system for their current model SCBA. Most SCBA manufacturers also provide similar voice communication systems for some earlier-generation SCBA.

The results for research question (b), “What standards, if any, apply to SCBA voice communication systems,” indicate that NFPA Standard 1981 (NFPA, 2007) articulates performance and testing requirements for SCBA voice communication systems. Although NFPA standards are consensus-based and non-regulatory, they are generally considered the de facto national standard, and all SCBA manufacturers certify their products to meet these standards as a business practice. In addition, many if not most fire departments specify compliance with NFPA standards when purchasing SCBA equipment.

For research question (c), "Which of the available SCBA voice communication systems provides improved voice communications under simulated emergency incident conditions," no specific literature was found evaluating or comparing any of the various SCBA voice communication systems or accessories, particularly under conditions encountered in emergency work. NFPA performance and testing requirements for SCBA voice communication systems are conducted in a controlled laboratory environment with the test subjects essentially in a rested state rather that at an elevated aerobic state, which is generally encountered while working at an emergency incident. Thus, this research project adds a previously untested element to the evaluation of voice communication systems. The results suggest that these conditions exacerbate the problem of voice communication clarity, particularly with similar sounding words. The results further suggest that none of the systems tested met the current 2007 NFPA pass threshold of 85%, although the three highest scoring systems evaluated did meet the previous NFPA pass threshold of 72%. This is likely due to the added non-NFPA test factor requiring the test subjects to recite their word lists while performing aerobic exercise at 70%-80% maximal heart rate.

The results for research question (d), "Which voice communication system, if any, is most effective for the Monterey Fire Department," are partially consistent with Cook's (2002) findings that radio interface systems provide clearer voice communication. The user questionnaire data indicate significantly higher satisfaction ratings for the wireless radio interface and voice amplification systems than the speech diaphragm and hard-wired radio interface systems. This data suggests that Monterey Fire Department SCBA users would prefer the first two communication systems over the latter two, however the results may reflect satisfaction ratings of the specific product evaluated rather than the technology in general. This data also indicates that, although the speech diaphragm achieved the highest average score value for voice communication clarity under simulated emergency incident conditions, it ranked third in user satisfaction among the five subject evaluators. The data further indicates that low system confidence was a common factor in the lower ratings of the speech diaphragm and hard-wired radio interface systems. Overall, the data suggests that Monterey Fire Department personnel would prefer the wireless radio interface or voice amplification communication system over the other two voice communication systems evaluated.

Organizationally, the results from this study provide data that will be useful in conducting a cost/benefit analysis of retrofitting the department's current SCBA with a voice communications system, as well as providing useful data to assist with the selection of a future replacement SCBA.

Recommendations

The next step for the Monterey Fire Department is to evaluate the Interspiro voice amplification system, and if it is determined to be as effective as the Sperian system evaluated in this study, conduct a cost-benefit analysis of retrofitting the department's current SCBA with that voice communication system.

Other researchers who may wish to study the effectiveness of SCBA voice communication systems should consider evaluating the effectiveness of the system in improving “heard” communication for the SCBA user as well as for a non-SCBA listener. Clarity of voice communications to and among SCBA users is critical to firefighter safety (USFA, 1999).

Readers should also be careful not to infer that other SCBA manufacturers’ products utilizing the voice communication technologies cited in this study would yield similar results. Other researchers should consider evaluating and comparing additional manufacturers’ examples of specific voice communication technologies.

Lastly, other researchers should consider evaluating the SCBA voice communication systems and technologies identified in this study under conditions that more closely approximate the real-life environment(s) where SCBA voice communication systems are regularly used and challenged, including controlled training exercises. Although this study provides data indicating the relative effectiveness of SCBA voice communication systems under simulated emergency incident conditions, the real measure of SCBA voice communication effectiveness ultimately lies in the confidence of the firefighters and incident managers utilizing them.

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Electronic Mail Solicitation of Test Subjects Appendix A

From: Sam Mazza

Sent: Friday, March 07, 2008 5:03 PM

To: John Alexiou; Chris Back; Dan Barker; Kathleen Battaglia; Buzz Cole; Mike Botkin; Jib Bowe; Jim Brown; John Caniglia; Felix Colello; Jim Courtney; Christopher Williams; Gemma Dailey; Kelly Davidian; Marcial Del Rosario; Graham Fenwick; Fire_Dept; Fire Firetemp; Christopher Fiske; Bob Flood; Paul Goodwin; Brendon Hamilton; Brian Holm; Neal Hurd; Pete Koeman; Ray LaFontaine; Vince Lombardi; Sam Mazza; Rob McCay; Michael Richardson; Kevin Murdock; Jarred Neal; Mitchell Ocon; Steve Pearson; Barry Perkins; Patrick Moore; David Potter ; Carmyn Priewe; Guy Pruitt; David Reade; Roger Reed; Gundy Rettke; Stewart Roth; Adam Rust; Larry Sands; Daniel Saracino; JD Sheldon; Steve Steinbach; Russell Stopper; Cosimo Tilly; Lou Valdez; Mike Ventimiglia; Art Webb; Robert Wilkins; Ken Zimmerman

Subject: Request for Assistance - SCBA Voice Communication Evaluation Project

Fire Service Colleagues,

As an element of the National Fire Academy Executive Fire Officer Program, I am required to complete an applied research project at the conclusion of each year’s resident course program. This year I have chosen to evaluate the effectiveness of various SCBA voice communication accessories, and I am soliciting ten persons to assist me with this research. Five persons are needed to serve as subject talkers, and will recite a list of 50 pre-selected words while wearing an SCBA with various voice communication accessories, while maintaining an aerobic heart rate on an exercise treadmill. This portion of the project should take approximately 5-6 minutes for each of the communications accessories, for a total of approximately 30 minutes. Volunteers will be permitted to rest between stages as desired. The other five persons will serve as subject listeners, selecting the words recited by the five talkers from a master word list. I anticipate no more than a 1 to 1-1/2 hour commitment for each volunteer assistant.

I am currently planning to conduct these two phases of the project over the March 29-30 weekend, dependent upon availability and delivery of test equipment. Volunteer assistants should have normal hearing.

I appreciate your consideration of this request for assistance with my research project. Please contact me if you are interested, or if I can answer any questions you may have.

Thank you,
Sam L. Mazza
Fire Chief
City of Monterey

Listener Speech Intelligibility Word List

Appendix B

Listener ID: __________
Talker ID: __________

Test Sequence:_____
Word List No. _____

Date: __________
Time: __________

1.	went	sent	bent
	dent	tent	rent
2.	hold	cold	told
	fold	sold	gold
3.	pat	pad	pan
	path	pack	pass
4.	lane	lay	late
	lake	lace	lame
5.	kit	bit	fit
	hit	wit	sit
6.	must	bust	gust
	rust	dust	just
7.	teak	team	teal
	teach	tear	tease
8.	din	dill	dim
	dig	dip	did
9.	bed	led	fed
	red	wed	shed
10.	pin	sin	tin
	fin	din	win
11.	dug	dung	duck
	dud	dub	dun
12.	sum	sun	sung
	sup	sub	sud
13.	seep	seen	seethe
	seek	seem	seed
14.	not	tot	got
	pot	hot	lot
15.	vest	test	rest
	best	west	nest
16.	pig	pill	pin
	pip	pit	pick
17.	back	bath	bad
	bass	bat	ban
18.	way	may	say
	pay	day	gay
19.	pig	big	dig
	wig	rig	fig
20.	pale	pace	page
	pane	pay	pave
21.	cane	case	cape
	cake	came	cave
22.	shop	mop	cop
	top	hop	pop
23.	coil	oil	soil
	toil	boil	foil
24.	tan	tang	tap
	tack	tam	tab
25.	fit	fib	fizz
	fill	fig	fin
26.	same	name	game
	tame	came	fame
27.	peel	reel	feel
	eel	keel	heel
28.	hark	dark	mark
	bark	park	lark
29.	heave	hear	heat
	heal	heap	heath
30.	cup	cut	cud
	cuff	cuss	cub
31.	thaw	law	raw
	paw	jaw	saw
32.	pen	hen	men
	then	den	ten
33.	puff	puck	pub
	pus	pup	pun
34.	bean	beach	beat
	beak	bead	beam
35.	heat	neat	feat
	seat	meat	beat
36.	dip	sip	hip
	tip	lip	rip
37.	kill	kin	kit
	kick	king	kid
38.	hang	sang	bang
	rang	fang	gang
39.	took	cook	look
	hook	shook	book
40.	mass	math	map
	mat	man	mad
41.	ray	raze	rate
	rave	rake	race
42.	save	same	sale
	sane	sake	safe
43.	fill	kill	will
	hill	till	bill
44.	sill	sick	sip
	sing	sit	sin
45.	bale	gale	sale
	tale	pale	male
46.	wick	sick	kick
	lick	pick	tick
47.	peace	peas	peak
	peach	peat	peal
48.	bun	bus	but
	bug	buck	buff
49.	sag	sat	sass
	sack	sad	sap
50.	fun	sun	bun
	gun	run	nun

Score: ___________

Talker Speech Intelligibility Word List #1 Appendix C

Instructions: Say: "Number [list sequence]; circle [list word] now."

Repeat for each word listed in order at 5-second intervals.

1. **went**
2. **told**
3. **pat**
4. **lace**
5. **kit**
6. **rust**
7. **teak**
8. **din**
9. **led**
10. **din**
11. **dug**
12. **sum**
13. **seep**
14. **not**
15. **rest**
16. **pip**
17. **back**
18. **gay**
19. **pig**
20. **pale**
21. **cape**
22. **shop**
23. **coil**
24. **tan**
25. **fit**
26. **name**
27. **peel**
28. **dark**
29. **heave**
30. **cup**
31. **thaw**
32. **then**
33. **pus**
34. **bean**
35. **beat**
36. **tip**
37. **kick**
38. **fang**
39. **shook**
40. **mad**
41. **rake**
42. **sale**
43. **fill**
44. **sill**
45. **bale**
46. **wick**
47. **peal**
48. **bug**
49. **sag**
50. **fun**

Talker Speech Intelligibility Word List #2

Instructions: **Say “Number [list sequence]; circle [list word] now.”**
Repeat for each word listed in order at 5-second intervals.

1. sent
2. cold
3. pad
4. lane
5. fit
6. bust
7. team
8. dill
9. fed
10. sin
11. dung
12. sun
13. seen
14. tot
15. test
16. pit
17. bath
18. say
19. fig
20. pace
21. came
22. mop
23. oil
24. tang
25. fib
26. game
27. eel
28. mark
29. hear
30. cut
31. law
32. den
33. pup
34. beach
35. heat
36. lip
37. kin
38. sang
39. book
40. mass
41. race
42. sane
43. kill
44. sin
45. gale
46. tick
47. peace
48. buck
49. sat
50. sun

Talker Speech Intelligibility Word List #3

Instructions: **Say “Number [list sequence]; circle [list word] now.”**
Repeat for each word listed in order at 5-second intervals.

1. bent
2. told
3. path
4. late
5. fit
6. gust
7. teal
8. did
9. red
10. tin
11. dub
12. sung
13. seed
14. got
15. rest
16. pick
17. bad
18. pay
19. big
20. page
21. cave
22. cop
23. toil
24. tap
25. fill
26. fame
27. keel
28. bark
29. heave
30. cud
31. raw
32. ten
33. pun
34. beat
35. meat
36. lip
37. kit
38. bang
39. took
40. math
41. rake
42. save
43. will
44. sin
45. pale
46. wick
47. peas
48. but
49. sass
50. run

Talker Speech Intelligibility Word List #4

Instructions: Say “Number [list sequence]; circle [list word] now.”
Repeat for each word listed in order at 5-second intervals.

1. went
2. fold
3. pack
4. lake
5. hit
6. dust
7. teach
8. dill
9. wed
10. fin
11. dug
12. sud
13. seethe
14. pot
15. best
16. pill
17. bat
18. day
19. dig
20. pave
21. cake
22. top
23. foil
24. tack
25. fig
26. same
27. heel
28. park
29. heal
30. cuss
31. jaw
32. pen
33. puff
34. bead
35. seat
36. dip
37. kill
38. rang
39. took
40. mat
41. race
42. same
43. hill
44. sill
45. male
46. sick
47. peak
48. bug
49. sag
50. bun

Talker Speech Intelligibility Word List #5

Instructions: **Say “Number [list sequence]; circle [list word] now.”**
Repeat for each word listed in order at 5-second intervals.

1. tent
2. sold
3. pack
4. lace
5. wit
6. just
7. tear
8. dim
9. shed
10. fin
11. dub
12. sum
13. seek
14. lot
15. west
16. pig
17. ban
18. gay
19. wig
20. pale
21. cane
22. cop
23. coil
24. tam
25. fin
26. name
27. feel
28. hark
29. heath
30. cub
31. saw
32. hen
33. puck
34. beak
35. beat
36. sip
37. king
38. hang
39. cook
40. man
41. ray
42. sale
43. will
44. sick
45. sale
46. kick
47. peach
48. buck
49. sat
50. gun

Talker Speech Intelligibility Word List #6

Instructions: **Say “Number [list sequence]; circle [list word] now.”**
Repeat for each word listed in order at 5-second intervals.

1. rent
2. gold
3. pass
4. lame
5. sit
6. rust
7. tease
8. dig
9. bed
10. win
11. dun
12. sun
13. seem
14. pot
15. nest
16. pin
17. bad
18. way
19. rig
20. pace
21. case
22. top
23. oil
24. tan
25. fizz
26. game
27. reel
28. dark
29. hear
30. cut
31. thaw
32. men
33. pub
34. beam
35. heat
36. hip
37. kid
38. gang
39. look
40. map
41. raze
42. sane
43. bill
44. sip
45. tale
46. lick
47. peat
48. buff
49. sack
50. fun

Talker Speech Intelligibility Word List #7

Instructions: Say “Number [list sequence]; circle [list word] now.”
Repeat for each word listed in order at 5-second intervals.

1. tent
2. cold
3. pan
4. lay
5. wit
6. bust
7. team
8. dip
9. led
10. pin
11. dung
12. sup
13. seen
14. tot
15. vest
16. pit
17. bat
18. say
19. big
20. pane
21. case
22. shop
23. soil
24. tang
25. fill
26. tame
27. peel
28. mark
29. heat
30. cuff
31. paw
32. then
33. pus
34. beach
35. neat
36. tip
37. kin
38. hang
39. hook
40. mat
41. rate
42. sake
43. hill
44. sing
45. bale
46. pick
47. peace
48. but
49. sad
50. nun

Talker Speech Intelligibility Word List #8

Instructions: Say “Number [list sequence]; circle [list word] now.”
Repeat for each word listed in order at 5-second intervals.

1. rent
2. fold
3. path
4. late
5. kit
6. gust
7. teal
8. did
9. fed
10. tin
11. duck
12. sub
13. seethe
14. got
15. test
16. pig
17. ban
18. pay
19. dig
20. pay
21. cape
22. mop
23. toil
24. tap
25. fin
26. came
27. reel
28. park
29. heap
30. cuss
31. jaw
32. den
33. pup
34. bead
35. feat
36. lip
37. kin
38. sang
39. shook
40. man
41. rave
42. safe
43. till
44. sit
45. gale
46. tick
47. peas
48. bun
49. sap
50. sun

Talker Speech Intelligibility Word List #9

Instructions: Say "Number [list sequence]; circle [list word] now."
Repeat for each word listed in order at 5-second intervals.

1. sent
2. sold
3. pat
4. lay
5. sit
6. dust
7. teach
8. dim
9. red
10. din
11. dud
12. sud
13. seek
14. lot
15. nest
16. pill
17. back
18. day
19. wig
20. pave
21. cake
22. hop
23. boil
24. tam
25. fizz
26. fame
27. feel
28. lark
29. heath
30. cub
31. saw
32. ten
33. pun
34. beam
35. meat
36. rip
37. kill
38. bang
39. book
40. mad
41. ray
42. sake
43. fill
44. sick
45. sale
46. sick
47. peak
48. bus
49. sass
50. run

Talker Speech Intelligibility Word List #10

Instructions: Say “Number [list sequence]; circle [list word] now.”
Repeat for each word listed in order at 5-second intervals.

1. went
2. gold
3. path
4. lake
5. wit
6. dust
7. teach
8. did
9. fed
10. tin
11. dug
12. sup
13. seen
14. pot
15. best
16. pip
17. ban
18. day
19. fig
20. pane
21. cake
22. mop
23. coil
24. tan
25. fizz
26. came
27. eel
28. mark
29. heal
30. cuff
31. jaw
32. then
33. pup
34. beach
35. neat
36. sip
37. kin
38. sang
39. shook
40. math
41. rate
42. same
43. hill
44. sin
45. gale
46. pick
47. peach
48. buff
49. sack
50. bun

Appendix D

Test Subject Target Heart Rate Calculation
(Karvonen Method)

Talker ID: __________ Date: __________

Name: ________________

Age-predicted maximum heart rate (APMHR) = **220** - subject age: _____ = _____

Heart rate reserve (HRR) = APMHR _____ - resting heart rate (RHR) _____ = _____

Lower target heart rate (LTHR) = (HRR _____ x 70% exercise intensity) + RHR ____ = _____

Upper target heart rate (UTHR) = (HRR _____ x 80% exercise intensity) + RHR _____ = _____

Target Heart Rate Range = (LTHR)_____ - (UTHR)_____

Communication System Evaluation Questionnaire **Appendix E**

Talker ID: __________ Test Sequence:_____ Date: __________

Instructions: Please rate the following factors relative to this specific SCBA voice communication technology and system. Please keep in mind that you are evaluating the technology represented by this communication system, not this specific manufacturer's product.

		N/A	Highly Unsatisfactory				→					Highly Satisfactory
1.	Donning time	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2.	Ease of communications system setup	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3.	Ease of communications system activation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.	Ease of communications system operation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
5.	Location of system activation control(s)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6.	Operation of system controls with gloves on	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7.	Facepiece configuration w/communications system	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8.	Weight of communications system	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9.	Bulk of communications system	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
10.	Tangle or snag potential	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
11.	Perceived ruggedness / durability	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
12.	Confidence in communication system	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
13.	Rating compared to other systems evaluated	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Communication Factors Questionnaire

Appendix F

Given your personal knowledge and experience with fire service SCBAs, please rate the relative importance of each of the following factors relating to SCBA voice communication systems. Your response to each of these questions before March 26 is appreciated.

1.	Ease of system activation and operation		
Extremely important to me		12	71%
Highly important to me		4	24%
Moderately important to me		1	6%
Minimally important to me		0	0%
Not important to me		0	0%
	Total	17	100%

2.	No system component set-up or inter-component connection(s) required for use		
Extremely important to me		4	24%
Highly important to me		6	35%
Moderately important to me		6	35%
Minimally important to me		1	6%
Not important to me		0	0%
	Total	17	100%

3.	Location of system activation switch (if applicable)		
Extremely important to me		6	35%
Highly important to me		8	47%
Moderately important to me		1	6%
Minimally important to me		2	12%
Not important to me		0	0%
	Total	17	100%

4. Operation of system switch(s) (e.g. power, PTT) with gloves on			
Extremely important to me		14	82%
Highly important to me		3	18%
Moderately important to me		0	0%
Minimally important to me		0	0%
Not important to me		0	0%
	Total	17	100%
5. Fully SCBA integrated system (i.e. no components attached to helmet, portable radio, etc.)			
Extremely important to me		6	35%
Highly important to me		6	35%
Moderately important to me		4	24%
Minimally important to me		1	6%
Not important to me		0	0%
	Total	17	100%
6. System enhances voice communications heard by SCBA user (i.e. includes speaker for SCBA wearer)			
Extremely important to me		7	41%
Highly important to me		8	47%
Moderately important to me		2	12%
Minimally important to me		0	0%
Not important to me		0	0%
	Total	17	100%
7. Microphone or voice diaphragm integrated into SCBA facepiece			
Extremely important to me		7	41%
Highly important to me		9	53%

Moderately important to me		1	6%
Minimally important to me		0	0%
Not important to me		0	0%
	Total	17	100%
8.	External, user-adjustable microphone or voice diaphragm		
Extremely important to me		1	6%
Highly important to me		7	41%
Moderately important to me		1	6%
Minimally important to me		6	35%
Not important to me		2	12%
	Total	17	100%
9.	Speaker integrated into SCBA facepiece		
Extremely important to me		6	35%
Highly important to me		8	47%
Moderately important to me		2	12%
Minimally important to me		1	6%
Not important to me		0	0%
	Total	17	100%
10.	System utilizes speaker incorporated into or attached to user's helmet; separate earpiece; or uses existing portable radio speaker		
Extremely important to me		0	0%
Highly important to me		1	6%
Moderately important to me		5	29%
Minimally important to me		3	18%
Not important to me		8	47%

Total		17	100%
11.	Configuration of SCBA facepiece with any integrated voice communication system components		
Extremely important to me		6	35%
Highly important to me		5	29%
Moderately important to me		5	29%
Minimally important to me		1	6%
Not important to me		0	0%
Total		17	100%
12.	Weight of SCBA facepiece with any integrated voice communication system components		
Extremely important to me		5	29%
Highly important to me		2	12%
Moderately important to me		7	41%
Minimally important to me		1	6%
Not important to me		2	12%
Total		17	100%
13.	Battery life for electronic componenets		
Extremely important to me		4	24%
Highly important to me		8	47%
Moderately important to me		4	24%
Minimally important to me		0	0%
Not important to me		1	6%
Total		17	100%
14.	Snag or tangle potential of any system component		

Extremely important to me		11	65%
Highly important to me		6	35%
Moderately important to me		0	0%
Minimally important to me		0	0%
Not important to me		0	0%
	Total	17	100%

15.	Please list up to five additional factors of significant importance to you relative to a SCBA voice communication system. Responses are limited to 50 characters per line.	
1.	Ruggedness / Durability	6
2.	Voice clarity	5
3.	Additional system bulk	4
4.	Added weight	3
5.	simplicity of design	2
6.	Reliablility	2
7.	Additional maintenance requirements	2
8.	Additional cost	2
9.	Availability of technical support	2
10.	Availability of spare parts	2
11.	Moisture/water resistance	2
12.	Dependability	1
13.	Additional donning time	1
14.	Comfort	1
15.	Compromised peripheral vision	1
16.	Start-up time for electrical components	1
17.	Firefighter locator capability	1